North Curtin Residential Area Microclimate Scenario Assessment

2024

EXECUTIVE SUMMARY

The North Curtin Residential Area Microclimate Scenario Assessment was conducted to evaluate the impact of a proposed development on the site's microclimate and to help identify heat mitigation measures that can be considered in the precinct design aimed at achieving 'net-zero heat gain' for new developments. The study utilised advanced microclimate simulation to model various design scenarios, and assessed their effectiveness in mitigating urban heat island (UHI) effects. The assessment focused on the North Curtin Residential Area, strategically located along key transport routes and adjacent to the Woden Town Centre. The site is earmarked for medium to high-density residential development under the ACT Government's vision for a more sustainable and liveable city.

Modelling approach

The modelling approach for the North Curtin Residential Area Microclimate Scenario Assessment involved using advanced microclimate simulation software, to create a detailed digital twin of the project site. This digital model incorporated various site characteristics, including building heights, roof types, road and pavement materials, vegetation, and soil profiles, sourced from client information, commercial and open-source GIS data, and aerial images. The simulation aimed to evaluate the effectiveness of different heat mitigation strategies by testing multiple future design scenarios (FDS). These scenarios included variations in tree canopy coverage, use of high albedo materials for roof, pavements and roads, irrigation methods, and building heights. The model was validated using on-site weather data collected through sensors, ensuring accurate representation of temperature, humidity, wind speed, and direction. The results provided insights into optimal design specifications to achieve 'net-zero heat gain', contributing to sustainable urban development in Canberra.

Results

Seven FDS were simulated, examining different combinations of heat mitigation strategies to identify the most effective measures for maintaining a comfortable microclimate. Table 1 below shows a high-level summary of simulation results illustrating key characteristics and objective of each FDS and their performance in terms of heat reduction. Modelling results suggest that to achieve 'no net heat gain' in the North Curtin Residential Area, the following design thresholds needs to be adhered to:

- No more than 21% of the area covered by buildings (with high reflectivity materials used).
- No more than 17% of the area covered by pavement (with high reflectivity materials used).
- No more than 9% of the area used for roads (low reflective material permissible).
- At least 53% of the area contains vegetation with minimum 29% tree canopy cover (30% tree canopy cover with matured trees is recommended given potential variability in simulation results).
- At least 36% of vegetated areas must have capacity to hold moisture for longer using means including soil irrigation, wetlands and raingardens.

Based on the simulations conducted in this assessment, in theory, if these thresholds are met, 'no net heat gain' in the precinct (compared to the baseline of summer 2018) can be achieved. However, certain factors should be considered carefully while implementing the site development. For example, it is noted that the site layout tested in this assessment is an early concept design and the final site design may need to be amended. An amended site layout to that tested in this assessment will require careful consideration of the layout of trees, which was found to have the most significant impact on heat reduction. For example, positioning trees in the high 'human traffic' areas (e.g., walkways and common outdoor areas) is critical for reducing heat exposure to outdoor users of the precinct and irrigated vegetated areas in the courtyard is recommended when compared to setback areas. Any change in building layout should also consider the dominant wind direction of the site and avoid creating any 'canyon impact' where heat can be trapped in some pockets between buildings. Results from the assessment also suggest that there are some areas of flexibility, particularly around building height if all other mitigation requirements are fulfilled.

Table 1: Heat gain or loss compared to Baseline across different FDS simulations. '-' value in green colour suggest heat loss and '+' value in red colour suggests heat gain

Scenarios	Key site characteristics	Canopy coverage of total site %	Average Canopy Diameter	Cool Roof	Cool Pavement (foot paths)	Cool Roads	Soil Irrigation	Maximum Building height	Change in daily average in °C		
									Potential Air Temperature at 1.5m height	Surface Temperature	Mean Radiant Temperature
Baseline	Site condition of summer of 2018								28.7	24.2	27.8
FDS 1	New development with residual trees only	15%	9.8m	X	X	X	X	21m	0.26	0.39	0.37
FDS 2	New development with moderate size new trees	21%	7.4m	X	X	X	X	21m	0.16	-0.11	-0.63
FDS 4	New development with relatively larger diameter trees	35%	10.4m	√	√	√	√	21m	-0.24	-1.41	-1.83
FDS 5	FDS 4 with taller buildings	35%	10.4m	√	√	√	√	30m	-0.24	-1.01	-2.83
FDS 6	New tree arrangement with no cool roads	29%	8.9m	√	√	X	√	21m	-0.04	-1.41	-1.93
FDS 7	FDS 6 with targeted vegetated roundabouts	29%	9m	√	√	X	√	21m	-0.04	-1.31	-1.73
FDS 8	FDS 6 with cool roads	29%	8.9m	√	√	√	√	21m	-0.14	-1.71	-1.63

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GLOSSARY AND ABBREVIATIONS

Albedo	A measure of the light reflected from a surface. This quantity ranges from zero to one where zero is a black surface that absorbs all light and one is a white surface that reflects all light. Higher albedo of a surface suggests higher reflectivity which can result in less absorption of sunlight by the surface resulting is less heat gain.
Emissivity	A measure of how quickly/efficiently a surface emits (releases) absorbed heat to return to its normal temperature. This measure ranges from zero to one where a value of one means that the surface is radiating the heat at the same rate that it is absorbing it. Typically, more reflective objects have lower emissivity.
Project site	North Curtin Residential Area in the ACT. The site has a northern boundary along Cotter Road, an eastern boundary along Yarra Glen and a southern boundary with the Yarralumla Creek channel and the existing developed residential area.
Urban Heat Island (UHI) effect	Urbanised areas that experience higher temperatures than outlying areas.
Mean radiant temperature	Mean radiant temperature (T_{MRT}) is one of the four environmental parameters that govern the human energy balance, and thus, play an important role in human thermal comfort.

ACT	Australian Capital Territory
CFD	Computational Fluid Dynamics
FDS	Future Design Scenarios
GIS	Geographic Information System
UHI	Urban Heat Island
The Bureau	The Bureau of Meteorology

1 BACKGROUND, AIMS AND OBJECTIVE

1.1 PROJECT SITE AND CONTEXT

The project site is located in the North Curtin Residential Area on Ngunnawal Country in the Australian Capital Territory (ACT). The site has a northern boundary along Cotter Road, an eastern boundary along Yarra Glen and a southern boundary with the Yarralumla Creek channel and the existing developed residential area. This site, comprising Block 13 Section 121 Curtin, Block 1 Section 114 Yarralumla, and Block 1 Section 77 Deakin, is currently an active horse agistment paddock managed by the Territory Agistment on behalf of the ACT Government. Refer to Figure 1 below for an illustration of the project site.

Figure 1: Aerial photo of North Curtin Area. Shaded area shows the proposed development site.

1.1.1 Proposed Development

In February 2020, a land transfer agreement between the Australian Government and the ACT Government facilitated the future growth of diplomatic missions in the National Capital, including the development of a new Diplomatic Estate. The remaining part of Block 5 Section 121 Curtin was rezoned from 'Broadacre' to 'Residential' use, paving the way for a new residential area, which will be delivered by the ACT Government.

Strategically located along the Canberra Light Rail corridor from City to Woden, the project site is adjacent to key transport routes and close to the Woden Town Centre, which is undergoing significant urban renewal. This makes the North Curtin Residential Area a prime location for transit-oriented development, supporting Canberra's vision of becoming a more compact, efficient, diverse, sustainable, resilient, liveable, and accessible city.

The project site has been proposed for development to sustain a residential block with medium or high density living while maintaining a 'net zero heat gain'. The development will be undertaken to comply with environmental controls in place by the *National Capital Plan* (2021) (National Capital Authority, 2021). This microclimate study is commissioned to identify development design thresholds and heat mitigations measures that can help this new development to achieve 'no net heat gain' from its baseline condition.

1.2 POLICY AND STATUTORY PLANNING CONTEXT

The National Capital Plan, administered by the Commonwealth, is the premier statutory and strategic land use plan for the ACT which ensures that Canberra and the Territory are planned and developed in accordance with their national significance. It establishes the general urban structure for Canberra and manages areas of national significance for their contributions to the national capital. The proposed North Curtin Residential Area site is a Designated Area in the National Capital Plan, and therefore the National Capital Authority (NCA) is responsible for approval of any proposed development or works. The Detailed Conditions of Planning, Design and Development for the North Curtin Residential Area are being drafted by the ACT Government, for consideration and endorsement by the NCA Board.

In 2019, the ACT Government released the *Canberra's Living Infrastructure Plan: Cooling the City* Report (Cooling the City Report), which outlines the City's vision to manage urban heat under climate change (ACT Government, 2019). This document outlines 15 actions to implement this vision which includes living infrastructure targets, outlining requirements of microclimate assessments, water sensitive urban design guides, etc. Action 3 and Action 4 of the Cooling the City Report, 'Microclimate Assessment Guide' and 'Microclimate Assessment Program', are highly relevant to this Report, as it focusses on mandating the use of microclimate assessment to inform policy and forward planning studies for centres, urban renewal projects and urban intensification precincts.

1.3 PURPOSE OF THIS REPORT

The focus of this Report is to report the results of the microclimate simulation for the North Curtin Residential Area and help establish the design thresholds and heat mitigation measures that are essential for the future development of the site to achieve a 'net-zero heat gain' from its baseline condition.

The main objectives of this assessment are to:

- Present a high-level overview of the current understanding of urban heat island in Canberra and best practice approaches of urban heat management that are relevant for the North Curtin Residential Area.
- Examine the microclimate of the current site (July 2023) and the baseline year (summer of 2018, which was chosen in discussion with the ACT Government) through onsite measurements and computer simulations.
- Examine the microclimate of the proposed future developed site by undertaking computer simulations including different design conditions and heat mitigation measures (e.g., cool roof, cool pavement, different canopy cover).
- Examine effectiveness of different heat mitigation options for the site and proposed design layout.
- Establish design thresholds for achieving 'no-net heat gain' from the future development compared to baseline site condition.

2 BEST PRACTICE APPROACH FOR MANAGING URBAN HEAT

2.1 URBAN HEAT ISLAND (UHI) IN CANBERRA

In general, Canberra experiences heatwaves during summer. For example, in 2016-17, there were 18 days between November and March when temperatures exceeded 35°C. This extreme heat increases the number of heat-related illnesses and deaths, specifically among the elderly and young children. Cold nights are also a feature of Canberra's climate, with 80 nights in 2017 recording below zero temperatures (Meyers, Devereux, Van Niel, & Barnett, 2017). It is important to highlight that climate change is likely to increase in hotter days and nights, and longer and more frequent heatwaves in the ACT and Canberra. Figure 2 below provides an indication of how the ACT's climate is likely to change.

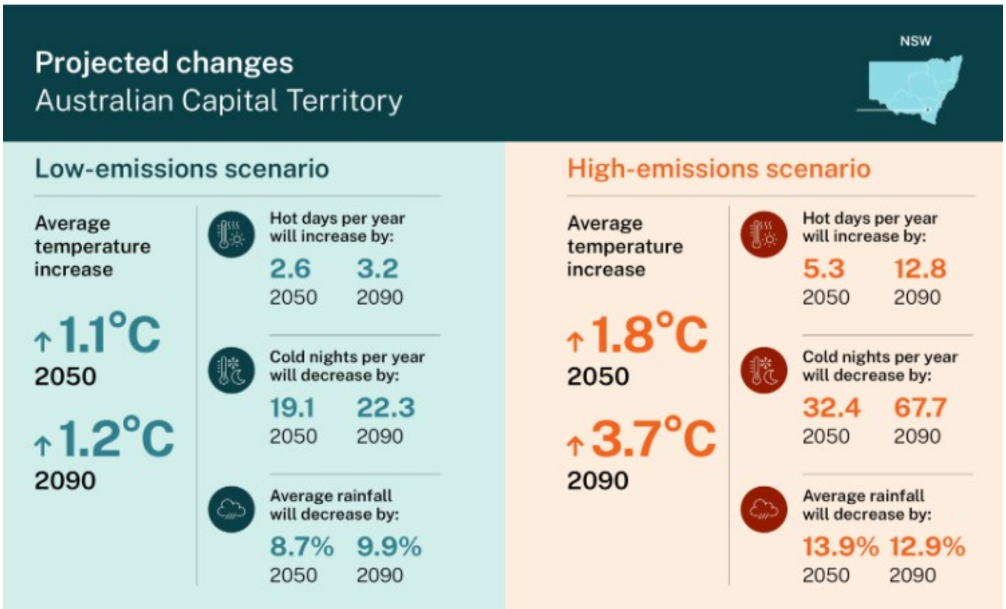


Figure 2: Climate projections for the ACT (AdaptNSW, n.d.)

Urban heat significantly affects liveability, as it impacts human health and wellbeing, economic productivity, the environment, infrastructure, and services. Urban built-up areas are susceptible to the Urban Heat Island (UHI) effect, which results in temperatures being generally higher than those in surrounding rural and natural areas. The extent of these temperature differences varies depending on weather conditions, season, and time of day, with the most significant disparities often occurring at night. During heatwave events, temperatures in highly built-up areas can become particularly elevated. This is because the weather conditions associated with heatwaves, such as low wind speeds and cloud-free skies, also favour the development of the UHI effect. While the UHI effect can be beneficial for urban residents during winter by providing warmer temperatures, it poses a significant risk during summer. In the hotter months, the increased temperatures associated with the UHI effect can lead to a higher likelihood of heat-related illnesses and fatalities. Hence, understanding the UHI effect is crucial for urban planning and implementing measures to mitigate its adverse impacts on public health.

A 2017 CSIRO study mapped the surface urban heat distribution across Canberra (Meyers, Devereux, Van Niel, & Barnett, 2017). This study used Landsat satellite imagery for this estimation and provides a good understanding of increased land surface temperature in different parts of Canberra at a city-wide broader scale. Refer to Figure 3 below. The study identified that:

- Canberra has a surface UHI at night in built-up areas that was around 8°C warmer in summer, and 6°C warmer in winter than surrounding rural areas (based on seasonal land surface temperature measurements at approximately 10:45pm Eastern Standard Time). This difference is largely caused by the night-time release of heat that has been absorbed during the day by buildings and pavements of urban areas.
- Cool areas on summer mornings typically have green irrigated vegetation, more tree cover, near lake edges, or are shaded.
- The characteristics of areas with above-average surface temperatures included the areas with large expanses of impervious surface cover such as rooftops and paving, and few trees, common in commercial and industrial areas, carparks, and new housing developments.

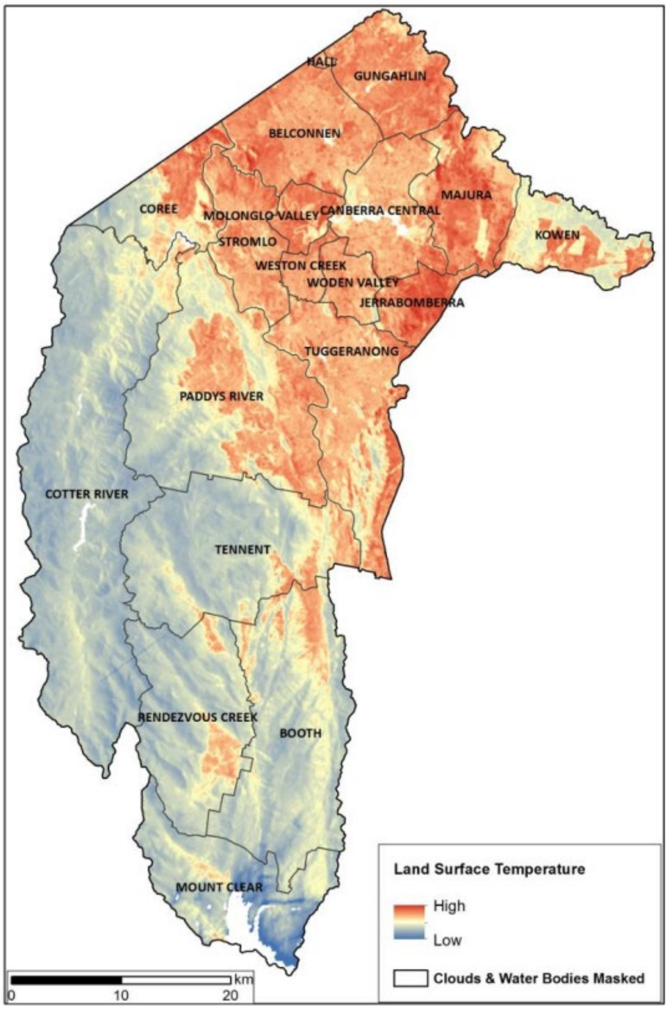


Figure 3: Land surface temperatures for the ACT for 9 February 2017, based on Landsat 8 thermal remote sensing imagery (Meyers, Devereux, Van Niel, & Barnett, 2017)

2.2 MANAGING URBAN HEAT

Urban heat mitigation and adaptation strategies implemented through urban planning is a major tool to achieve reduction in adverse impacts of heat, particularly in the consideration of the effects of climate change and urban sprawl (Filho, Icaza, Klavins, Morgan, & Neht, 2018). Urban heat is best managed using a suite of options and not being overly dependent on a single option alone (see Figure 4 below). A number of these options are outlined in the Cooling the City Report (ACT Government, 2019). Examples include:

- Use of vegetation such as trees
- Replacing heat absorbing infrastructure such as car parks with perforated surfaces (vegetated areas, wetlands, etc.)
- Using cool materials to increase reflectivity and emittance (cool roofs / cool and permeable paving), and
- Use of water sensitive urban design.

This section provides further information on:

- Trees and vegetation
- Cool pavements
- Cool roofs, and
- Green roofs and facades.

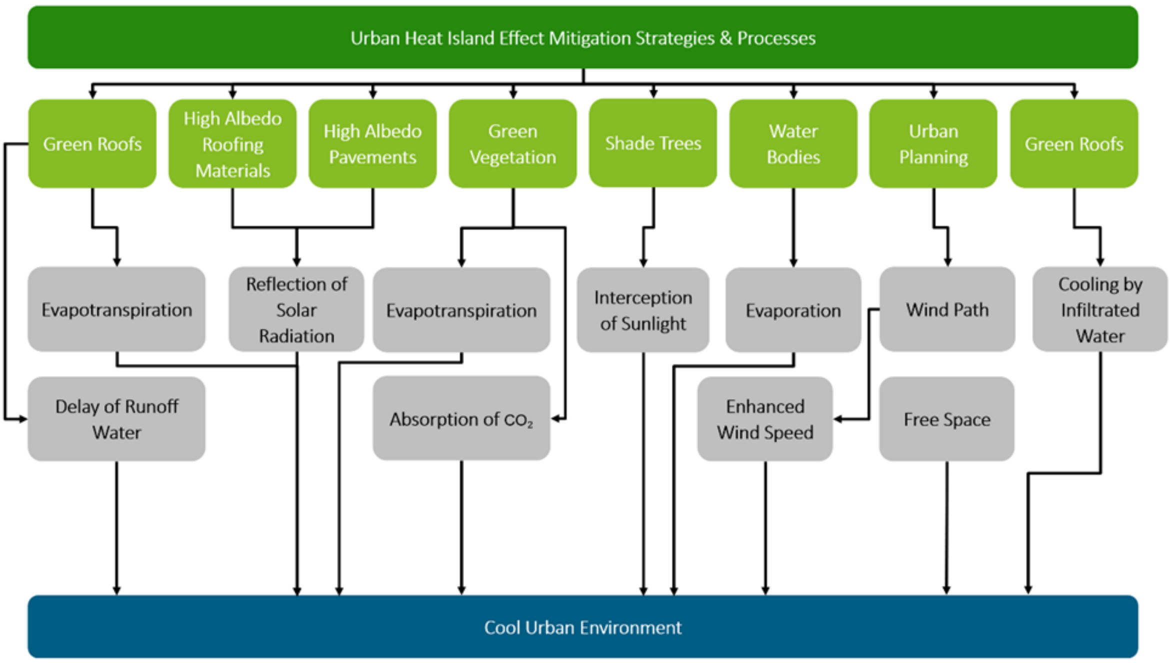


Figure 4: Urban Heat Management Options (Nuruzzaman, 2015)

2.2.1 Trees and Vegetation

Trees and vegetation help cool urban environments through a combination of shade provision and evapotranspiration. Shading of surfaces by tree canopy can reduce the surface and air temperature significantly compared to non-shaded open areas (Pataki, et al., 2021). Benefits of trees and vegetation cover in urban heat mitigation and management are listed below (Coutts & Tapper, 2017) (Nice, 2021):

- Vegetation, especially trees, provides shade to surfaces like roads and buildings, reducing the amount of sunlight absorbed by these surfaces. Shaded surfaces stay cooler compared to exposed areas, which typically heat up and release that heat into the air. By blocking direct solar radiation, vegetation prevents surfaces from reaching higher temperatures, reducing the overall heat in urban areas.
- Tree canopies block incident solar radiation and shade the surrounding urban surfaces, leading to reduction in the radiant temperature below the canopy cover which can provide significant improvements in the high temperature conditions during the day.

- As the fraction of vegetation cover increases, land surface typically decreases. A study found that, during the day, a 10% increase in vegetation cover can result in a 1.2°C reduction in land surface temperature (Coutts, et al., 2016).
- The reduction in air temperature from increased vegetation is primarily related to the reduction in ground heat storage because of shading and insulation of the surface. By increasing the vegetation surface cover, less heat is absorbed and stored in the ground and buildings during the day, which results in less heat being re-emitted at night.
- In urban environments, irrigation amplifies the cooling effect of vegetation. A study found that areas with more pervious surface cover (which includes vegetation and water) showed more pronounced cooling, and higher levels of irrigation led to lower temperatures during a heatwave (Cheung, Nice, & Livesley, 2024) (Broadbent, Coutts, Tapper, & Demuzere, 2018).
- While trees provide a cooling effect through the provision of shade and moisture from evapotranspiration, they can also impede wind flow and trap heat at night, causing slight heat effects.
- Tree species choice is crucial for heat mitigation, as species vary in canopy density, leaf structure, and water needs. Effective selection maximises shade, cooling, and resilience to urban heat.

2.2.2 Cool Pavements

Cool pavements are pavements which maintain a lower surface temperature and mitigate urban overheating better than more traditional pavements by using highly reflective material or coating. This material or coating is based either on the use of materials with high reflectance in solar radiation and high emissivity in infrared radiation (i.e., reflective pavements), or the use of latent heat of evaporation (evaporative cooling) to reduce their surface temperature (i.e., water retentive pavements) (Kappou, et al., 2022).

Generally, reflective pavements are most suited for climate zones with a high amount of incoming solar radiation, and permeable pavements are better suited for climate zones where weather patterns follow tropical fluctuations with high moisture content (Kousis & Pisello, 2023). While cool pavements may reduce the surface temperature of the pavement itself, the air temperature above is not directly related and therefore may not decrease (Santamouris, 2016). It is also important to note and consider that there is currently limited studies evaluating cool pavements under real-world outdoor conditions (Kousis & Pisello, 2023) (Wang, Wang, Kaloush, & Shacat, 2021).

2.2.3 Cool Roofs

Cool roofs are one of the most efficient and cost-effective solutions for reducing the energy demand and improving the indoor thermal comfort condition of buildings, especially in areas with cooling-dominated weather conditions (Garshasbi, et al., 2023). A cool roof is designed to reflect more sunlight than a conventional roof, absorbing less solar energy, to lower the temperature of the building. Cool roofs are made of materials that are engineered to have a high reflectivity, therefore reducing the surface temperature (Zhang, Fukuda, & Liu, 2019).

Refer to Figure 5 below for a visualisation of how cool roofs work to reflect solar radiation.

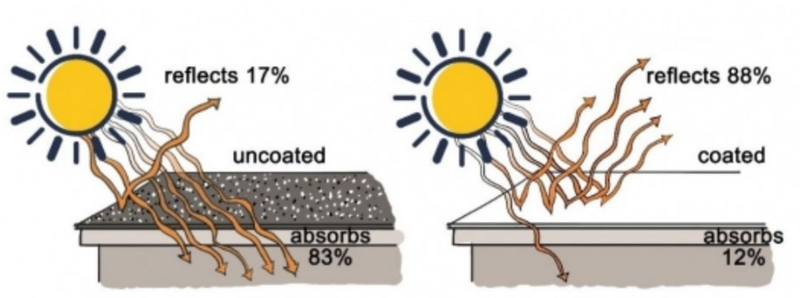


Figure 5: Illustration of how cool roofs reflect more solar radiation than they absorb (Razzhigaeva, 2022)

Australian studies on the application of cool roofs have identified the following:

- The performance of cool roofs is primarily affected by albedo. If, for example, the albedo is decreased due to dirt accumulation, the city-scale cooling effect of cool roofs can be reduced (Li, Bou-Zeid, & Oppenheimer, 2014).
- A national study funded by the Department of Industry, Science, Energy and Resources identified that the outdoor air temperature in major Australian cities can reduced by 2.1-2.5°C with solar reflective roofs. The study also indicated that city-scale use of cool roofs would reduce the maximum peak outdoor air temperature, which occurs daily at 2pm, by an average of 1.5-2°C during summer (UNSW, 2017).
- A 2018 Melbourne-based study observed that the net radiation at midday was 78% lower for cool roofs than for a vegetated rooftop during summer (Jacobs, Gallant, Tapper, & Li, 2018).
- Cool roofs have the greatest cooling potential in residential buildings, reducing heat and energy consumption by potentially up to 63.6%, with a slight, but still significant, impact on office and commercial buildings (Garshasbi, et al., 2023).
- Cool roofs have the highest impact on low-rise buildings with low levels on insulation, but can still be noticeable in high-rise buildings with high levels of insulation.
- During the summer months, cool roofs are estimated to significantly reduce indoor air temperature and the number of overheating hours. The study found that cool roofs could reduce the maximum indoor air temperature by up to 12°C (Garshasbi, et al., 2023).

Notably, there is a degree of fragmentation of research and data on cool roofs, which impacts the overall understanding of the success of cool roofs as a method to reduce urban overheating (AURIN, 2024).

2.2.4 Green Roofs and Facades

Green roofs are multi-layered structures with the outer layer consisting of vegetation (Razzaghmanesh, Beecham, & Salemi, 2016). Green roofs are beneficial for urban heat management as it increases the evapotranspiration in urban areas through the soil and plants, reducing the air temperature at the roof level (Li, Bou-Zeid, & Oppenheimer, 2014). They can also bring amenity and enhance aesthetic value, contribute to energy savings, noise reduction, and act as a stormwater runoff mitigation tool. A Sydney-based study found that green roofs contributed to a reduction in rooftop temperatures up to 20°C when ambient temperatures exceeded 40°C, as well as improved heat flow of up to 55.54% (Fleck, et al., 2022).

There are two types of green roofs:

- Extensive green roofs: Low maintenance green roofs and often include plants such as succulents.

- Intensive green roofs: Similar to a conventional park or garden and have a range of species. These roofs are generally higher maintenance than roofs with succulents.

Priority locations for green roofs includes sun exposed roofs, poorly insulated buildings, low and large buildings, and dense areas with little available ground space (Nice, 2021).

When adopting green roofs as a heat mitigation strategy, it should be noted and considered that:

- The performance of green roofs is affected by soil moisture. Under drought conditions when soil moisture is close to its wilting point, the cooling effect provided by green roofs may be almost eliminated. Therefore, under dry conditions, irrigation is critical to ensure the continued maintenance of the cooling effects of green roofs (Li, Bou-Zeid, & Oppenheimer, 2014).
- Vegetation is likely to be more effective with higher temperatures and lower relative humidity (Razzaghmanesh, Beecham, & Salemi, 2016).
- The impact of additional green infrastructure on the fire safety of buildings should be considered, as it has been suggested that green roofs and walls may constitute as a fire hazard, particularly during periods of drought.
- Green roofs add significant weight to buildings, requiring structural assessments. Inadequate consideration of additional weight in building design can lead to structural stress, damage, posing safety and financial risks.
- Benefits of green roof are localised and unless they are applied widely across the precinct, a precinct scale benefit in heat reduction is difficult to achieve. When green roofs are compared with other heat mitigation measures (e.g., cool roof, tree canopy etc.), its relative high cost and maintenance requirement makes it relatively unattractive. Further, green roofs primarily cool rooftop surfaces but have limited impact on ground-level temperatures, where most human activity and heat exposure occur.

2.3 MANAGING URBAN HEAT IN CANBERRA

There are multiple strategies that can help reduce heat generation within urban areas. A number of these options are outlined in the Cooling the City Report (ACT Government, 2019). These include planning and design incorporating cool building materials, pavements, and road surfaces, and increasing the amount of vegetation and water on the site. Examples include:

- Use of vegetation such as trees and other shade forming species
- Replacing heat absorbing infrastructure such as car parks with perforated surfaces (for example, vegetated areas and wetlands)
- Using cool materials to increase reflectivity and emittance (cool roofs / cool and permeable paving)
- Use of urban water (lakes, ponds, water sensitive urban design and water features), and
- Use of water sensitive urban design.

A separate microclimate study was conducted in Canberra for the redevelopment of the Dairy Road Precinct which investigated the effectiveness of different heat mitigation measures and identified that tree canopy, use of permeable surfaces and positioning of building and roads to ensure optimum flow of winds (see Table 2) are the most effective ways to mitigate heat at the precinct level (BMT, 2022). These insights are further tested in this North Curtin Residential Area Microclimate Scenario Assessment for their appropriateness for the North Curtin Residential Area, and further discussed in Section 5 (Results and Discussion) of this Report.

Table 2: The effectiveness of different heat mitigation options in Canberra (Insights generated from microclimate simulation in similar projects conducted in Canberra)

Potential mitigation measures	Microclimate simulation assessment overview	Contribution of the option to heat reduction.
Low thermal mass, high albedo and or high emissivity building materials and/or finishes	Use of high albedo materials in roofs shows reduction of air and surface temperature.	Medium
Inclusion of canopy trees to achieve an overall minimum of 30% shade across the precinct	Use of tree canopy in the site can result in net heat loss.	High
Water retention in the soil through irrigation	Water sensitive urban design features such as rain gardens, wetlands, active irrigation can help retain rainwater and moisture in the soil for longer which helps in improve thermal condition on the site, specifically during heatwaves. Native vegetation ground cover with associated high soil moisture can have high effectiveness in reducing thermal load.	High
Use of water features	Water features can result in localised temperature reduction.	Medium, but benefits are highly localised
Appropriate location of open space and buildings	Positioning of buildings considering predominant wind direction can help reducing heat gain in pockets in the precinct.	High
Other types of cooling measures such as green roofs, vertical gardens	Use of high albedo materials in roofs shows reduction of air and surface temperature.	Low (at a precinct scale)

3 METHODOLOGY

3.1 OVERVIEW

This section provides an overview of our approach to deliver the North Curtin Residential Area Microclimate Scenario Assessment.

Table 3: Overview of Approach

Stages	Objectives	Key activities
1. Project inception	Set the project up for success	1.1. Project Inception Meeting. 1.2. Ongoing project management.
2. Calibrate microclimate simulation model for the existing site	Develop a microclimate simulation for the existing site	2.1 Install the mini weather station and temperature sensors on site and measure site data for a week. 2.2 Develop digital twin of the existing greenfield site within Computational Fluid Dynamics (CFD) software to simulate microclimate of the current site. 2.3 Calibrate the microclimate model of the site using on-site measurement of weather variables (temperature, wind speed/direction, humidity, etc.). 2.4 Discuss baseline year for simulation comparison with the ACT Government and simulate microclimate of the baseline year.
3. Collect future precinct design from planners	Understand future site layout	3. Engage with the ACT Government and its appointed Planners to collect indicative future site design for the North Curtin Residential Area. This is the starting point of microclimate simulation of future site.
4. Microclimate simulation for future site vision	Understand temperature profile of future site	4.1 Use the collected indicative future site design layout to develop a digital twin of the site within the CFD computer simulation software, incorporating buildings, roads, vegetation, parking, and other features envisioned for the future site. 4.2 Run microclimate simulations for 7 scenarios incorporating different heat mitigation options to help define the design thresholds for the site to be within the limit of no net heat gain.
5. Reporting on findings	Visualisation and communication of results	5.1 Develop draft report for review. 5.2 Present project results and designed thresholds to the project team. 5.3 Deliver final report, including recommendations and supporting illustrations/visualisations.

3.2 MANAGING URBAN HEAT USING EVIDENCE-BASED MICROCLIMATE SIMULATIONS

The extent to which the UHI management options discussed above will be effective in reducing heat in a specific site is determined by site characteristics, such as:

- Existing urban fabric
- Materials of buildings and surfaces
- Arrangement of urban layout
- Extent of vegetation, and
- Local climatic conditions.

A microclimate simulation is an advanced, fine scale modelling technique that simulates the microclimate of a site (like a digital twin) and can be used to evaluate the effectiveness of UHI management options in reducing urban heat.

3.2.1 Definition and Use of Microclimate Simulation

The microclimate of a site is controlled by a multitude of different man-made and natural elements forming the urban landscape. They all have their individual characters and constitute in their own way to the formation of wind flows, radiation patterns and air temperature. Simulation of these microclimate features through computational fluid dynamics software enables users to understand the impact of different site features on its microclimate. Microclimate simulation models analyse micro-scale thermal connections in urban environments.

The model utilises the thermodynamic procedures taking place at the ground surface between building features (e.g., walls and roofs), roads, trees, etc. In addition to the calculation of fluid dynamics features like turbulence and air flow, the software considers all kinds of solar radiation: direct, reflected and diffused and estimates different microclimate parameters. This allows planners, architects, and engineers to make evidence-based design decisions for urban design.

3.3 DESIGNING MICROCLIMATE SIMULATION SCENARIOS TO UNDERSTAND EFFECTIVE HEAT MITIGATION OPTIONS FOR THE FUTURE DEVELOPMENT SITE

3.3.1 The North Curtin Simulation

In this study the commercial microclimate simulation software, Envi-met, was used for simulating North Curtin's microclimate. Envi-met software was developed by Professor Michael Bruse and has been used widely in different scientific and commercial studies (Elnabawki, Hamza, & Dudek, 2013); (Ambrosini, Galli, Mancini, Nardi, & Sfarra, 2014); (Crank, Sailor, Ban-Weiss, & Taleghani, 2018) (Simon, et al., 2018); (Farhadi, Faizi, & Sanaieian, 2019); (Shinzato, Simon, Duarte, & Bruse, 2019); (Simon, Sinsel, & Bruse, 2020); (Perera, Nayanajith, Jayasinghe, & Premasiri, 2021); (Jaafar, Lakkis, & Yeretzian, 2022).

To understand the differences in microclimate between current site and future built form outcomes, Deloitte designed several microclimate analysis scenarios. A baseline year was selected in discussion with the ACT Government team. The site conditions of summer of 2018 were selected as baseline of simulation models with which modelled thermal conditions of the future site was compared to Multiple Future Design Scenarios (FDS) for the North Curtin Residential Area were designed to test the application of different combinations of heat controls which could be readily applied at North Curtin and to understand their effectiveness.

These FDS are discussed in further details in Section 4.5 (Constructing and simulating future design scenarios) of this Report.

3.4 INDICATORS OF 'NET HEAT GAIN' OR 'LOSS'

To understand the net heat gain or loss of heat in the simulated future development site, two types of analysis were conducted. First, the average temperature of a given summer day was estimated for each of the scenarios and compared with the baseline. Second, four different timeframes within a given day were evaluated separately to understand the thermal condition of the future site at different points in the day.

Table 4: Times of the day used for analysis and their rationale

Times	Rationale of use
Mid-morning 9am	This time captures the morning temperature as the site begins to warm. It is typically cooler but provides insight into the rate of temperature rise and early sun exposure effects.
Early Afternoon 12pm	This represents peak solar irradiance when the sun is at its highest. It captures maximum heating conditions, making it crucial to assess how the site absorbs heat during the hottest part of the day.
Mid-afternoon 3pm	By this time, the site has been subjected to prolonged sun exposure, giving insights into how heat accumulates and whether heat dissipation or further accumulation occurs in the afternoon. If exposed to excessive heat during late afternoon while conducting outdoor activities, heat can cause dehydration, fatigue, heat exhaustion, or heatstroke, especially in vulnerable groups like children and the elderly.
Mid-evening 9pm	After sunset, the heat retention and cooling behaviour of the site can be observed. This time is important for evaluating night-time cooling rates and heat dissipation efficiency. With excess nighttime heat being associated with increased hospitalisations and adverse human health risks, it is important to capture this time in the analysis (Guo, Chan, Qiu, Wong, & Ho, 2024).

3.4.1 'Net Heat Gain or Loss' Calculation

Indicators were calculated from the results of each microclimate simulation to understand whether design conditions add or reduce net heat compared to baseline site conditions, as illustrated below at Table 5. This was done by exporting the temperature values from the cells of each model and calculating the average temperature of all cells. The outermost cells were excluded from analysis to reduce the potential of edge effect anomalies.

Table 5: Adopted indicators of "heat gain or loss" from future development

Times	Indicators
Mid-morning 9am	Air temperature T_a
	Surface Temperature T_s
	Mean Radiant Temperature T_{mrt}
Early Afternoon 12pm	Air temperature T_a
	Surface Temperature T_s
	Mean Radiant Temperature $_{Tmrt}$
Mid-afternoon 3pm	Air temperature T_a

	Surface Temperature T_s
	Mean Radiant Temperature T_{mrt}
Mid-evening 9pm	Air temperature T_a
	Surface Temperature T_s
	Mean Radiant Temperature T_{mrt}

4 MICROCLIMATE MODEL DEVELOPMENT FOR NORTH CURTIN

4.1 CONSTRUCTING THE MICROCLIMATE MODEL OF THE EXISTING SITE

To develop a microclimate model for the existing North Curtin Residential Area (2024), a digital twin of the site was constructed within the CFD computer simulation software by incorporating indicative site information, such as potential building, road, vegetation, and parking information. This was done using multiple sources, such as client information, commercial and opensource Geographic Information System (GIS) data, and high-resolution aerial images of the site.

Information about existing site such as vegetation and soil characteristics of the site, building (height and roof materials) and roads surrounding the site were collected from inspecting aerial imagery. A tree study of the existing site was conducted by the ACT Government team and information from that was used to allocate tree types, height, and canopy diameter of the current site.

Information such as indicative building heights, roof types, road and pavement material, vegetation types and tree species, and soil type of future development site were collected from the ACT Government appointed Planners and was incorporated in the model to develop a 3D representation of the future site. See Table 6, which lists the data characteristics and sources utilised in the model setup (baseline and all FDSs).

Table 6: Data characteristics and sources

Object type	Characteristics	Data source	Material or feature type
Buildings	Roof height (m)	ACT Government Planners	N/A
	Floor height (m)	ACT Government Planners	N/A
	Roof material	ACT Goverment Planners	• Roofing tiles • Concrete
	Wall material	ACT Government Planners	• Concrete • Plaster • Burned and aerated brick
Pavement	Built surface material	ACT Government Planners	• Light concrete
Road	Built surface material	ACT Government Planners	• Asphalt
Vegetation (shrubs / trees)	Vegetation height and canopy width (m)	ACT Government tree survey	• Trees • Shrubs / hedges
Vegetation (grass)	Type of grass and soil	ACT Government tree survey	• Grass • Soil profile

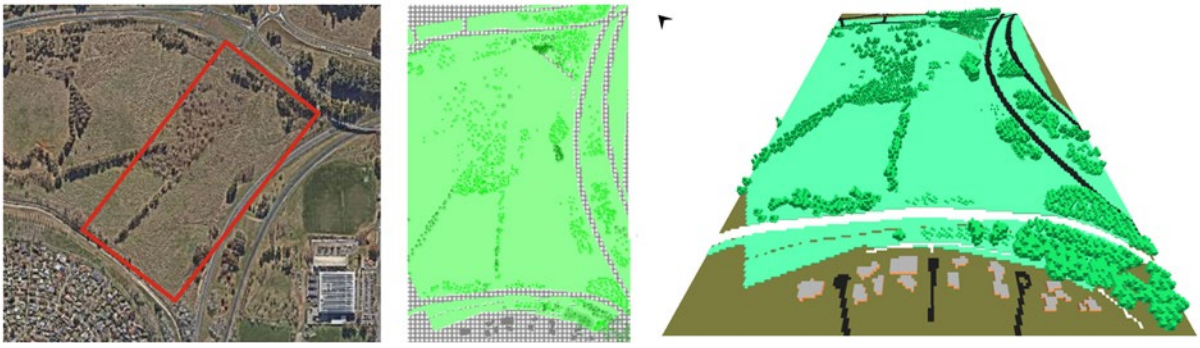


Figure 6: Various representations of study area to support model setup. Left: Google Earth aerial image; Middle: 2D model of current site showing roads and vegetation; Right: 3D illustration of the model site

Along with natural surfaces and elements of site such as soil, grass, and trees, the major construction materials used for the future development of the site include:

- Concrete (for building and footpath pavement)
- Brick wall with plaster (for building), and
- Asphalt or bitumen (for road).

Table 7: The reflectivity characteristics of different surfaces (Santamouris, 2016; Sharma et al., 2016; Zhang, Fukuda and Liu, 2019; Bherwani, Singh and Kumar, 2020; BlueScope, 2020; He et al., 2020; Pfautsch and Wujeska-Klause, 2021)

Surface type	Albedo	Emissivity	Interpretation
Asphalt pavement	0.1	0.9	Asphalt does not reflect a large portion of solar energy and also holds heat for longer compared to other materials such as steel.
Concrete roof and pavement	0.4	0.9	Concrete has a moderate ability to reflect solar energy and holds heat for longer compared to other materials such as steel.
Steel roof and wall	0.5	0.2	Steel has a moderate ability to reflect solar energy but does not hold heat as long as concrete or asphalt as it transfers heat quickly.
Brick wall with plaster	0.4	0.9	Concrete plaster on top of brick wall has a moderate ability to reflect solar energy and holds heat for longer compared to other materials such as steel.
Bare Soil (sandy loam/Sandy clay loam profile)	0.2	0.98	Bare soil does not reflect a large portion of solar energy and holds it for longer.
Grass	0.2	0.3	Grass has low reflectivity of solar energy but does not hold heat for long.

The reflectivity of materials (e.g., buildings, pavements, bare soil, and vegetation) needed to be assigned for both baseline and future site. Reflectivity is measured as albedo and determines the extent that solar radiation will be reflected (or absorbed) by the surface. For these values, Deloitte used information that are available from published scientific studies. Table 7 below describes the reflectivity characteristics of different surfaces in the model where the following definitions apply:

- Albedo: A measure of the light reflected from a surface. This quantity ranges from zero to one where zero is a black surface that absorbs all light and one is a white surface that reflects all light. Higher albedo of a surface suggests higher reflectivity which can result in less absorption of sunlight by the surface resulting in less heat gain.
- Emissivity: A measure of how quickly/efficiently a surface emits (releases) absorbed heat to return to its normal temperature. This measure ranges from zero to one where a value of one means that the surface is radiating the heat at the same rate that it is absorbing it. Typically, more reflective objects have lower emissivity.

4.2 SIMULATING THE NORTH CURTIN MODEL

Two microclimate simulations were conducted for the current North Curtin Residential Area:

- The ‘calibration model’, which was run with a weather condition of 15 July 2023, and
- The ‘baseline model’, which was run with climate condition of 21 December 2018.

The first simulation helped calibrate the North Curtain model as weather monitoring instruments were deployed on site for a week from 13 July 2023 to 21 July 2023. The second simulation (December 2018) was conducted to establish a baseline against which the heat gain or loss of the future site will be compared. This selection of baseline was made collaboratively in discussion with the ACT Government team.

Wind direction plays a critical role in microclimate simulation and changes in wind direction can influence model results. Therefore, Deloitte has utilised historical wind roses from the Bureau to determine the predominant wind direction in summer and winter months (see Figure 24 in Appendix A). The predominant wind direction in summer in this area is from the north-west. The predominant wind direction in winter in this area is from the north-north-west. Based on this, for this study wind direction from the north-west was used for the baseline summer model run and north-north-west for the calibration winter model run. The model was simulated for 16 hours of the selected simulation days (from 5am to 9pm).

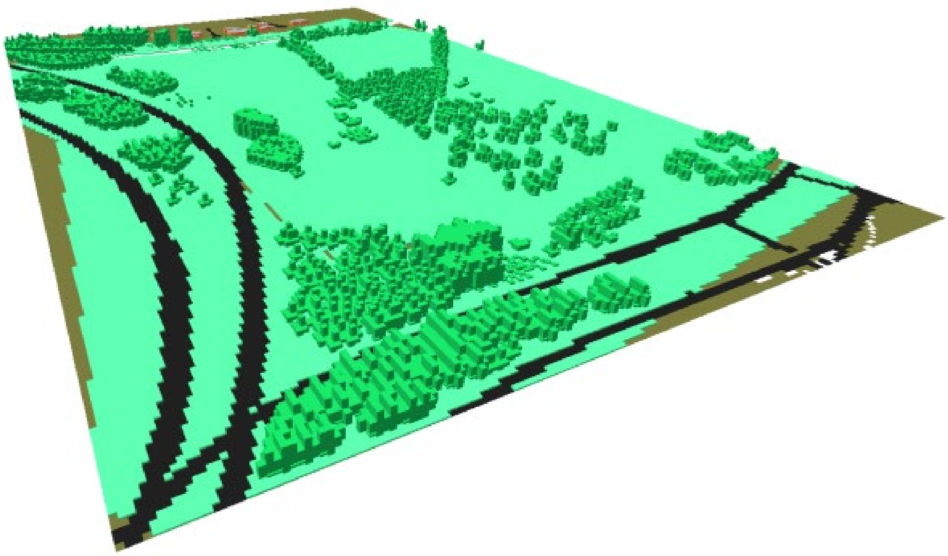


Figure 7: 3D model of the current site (North-East view)

4.3 MODEL CALIBRATION

The first objective of the model calibration was to ensure that the model of the study site provided representative microclimate results in terms of its temperature, humidity, and wind speed.

To calibrate the model, weather observation data of 15 July 2023 was collected from the Bureau (Canberra Airport station ID 070351) for a range of variables (air temperature, humidity, and wind speed). This data was used as the boundary condition for the calibration model simulation. Simulated results of the calibration model were then compared with onsite measurements taken on 15 July 2023 to check the extent to which the simulation of Model 2023 matched with site measurements.

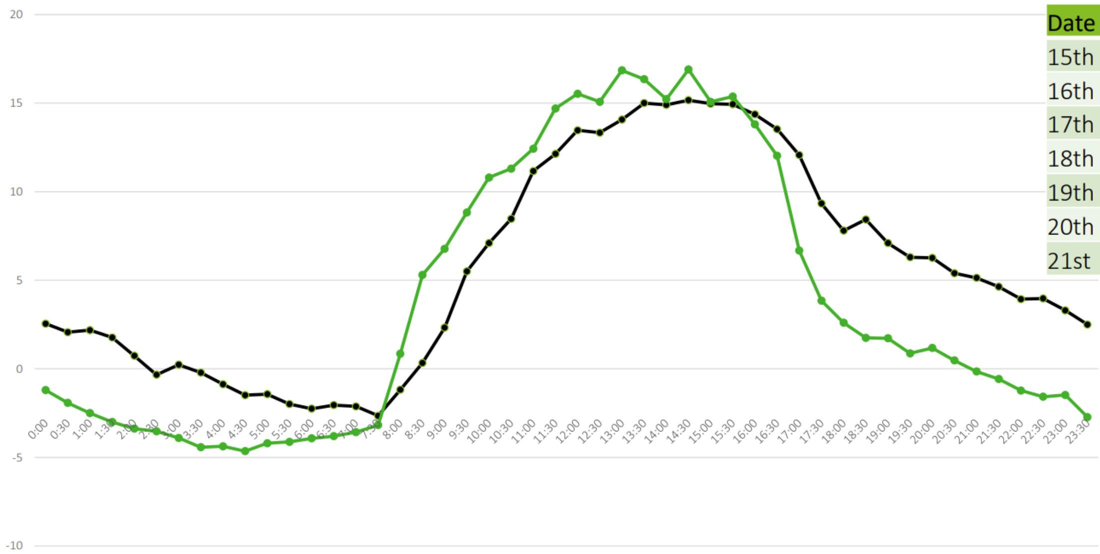
4.3.1 Collection of Onsite Data to Calibrate Microclimate Model of the Existing Site

To calibrate the 3D microclimate model of the North Curtin Residential Area, sensors and weather stations were installed on site to collect different climate parameters of the study area. Data was collected every hour for a week from 13 July 2023 to 21 July 2023. Measured paraments include dry bulb and wet globe temperature, humidity, wind velocity, wind direction, air temperature and surface temperature. Five sensors were deployed, however two were lost in the process of collection, resulting in two recording air temperature and one recording surface temperature. A mini weather station (Kestrel) recorded the remaining parameters. These sensors targeted capturing microclimate variation across different parts of the site. Figure 8 below shows the location of installed sensors, and Figure 9 shows images of the installed sensors. On site parameters were compared with the Bureau weather data of the day from the Canberra Airport station ID 070351 (see Figure 10). On that day, the North Curtin Residential Area was slightly cooler in the early morning and night compared to the Airport.

Once the calibration model simulation was completed, hourly simulated air temperature data from the three grids of the onsite sensors were extracted from the model outputs for analysis of how well model prediction matched onsite measurements at different points within the site. The results confirmed that data at all sites were highly correlated (r>0.9) providing a good confidence in the Model 2023 simulation results. The results showed the simulation, while highly correlated, was slightly cooler than the onsite measurements.

Figure 8: Location of installed sensors for North Curtin

Figure 9: Photos of installed sensors



Date	Max T
15th	19.3
16th	20.6
17th	18.6
18th	16.1
19th	16.9
20th	14.4
21st	17.6

Figure 10: Comparison of average hourly temperature data from the Bureau Canberra Airport weather station (ID: 070351) and in situ site weather observations (average of all sensors)

4.4 CONSTRUCTION OF THE BASELINE MODEL

Once model calibration was completed, the same model was run using the agreed baseline weather condition of December 2018 (Figure 11 below). Results of this baseline simulation were used for comparison with future site condition to understand net heat gain or loss.

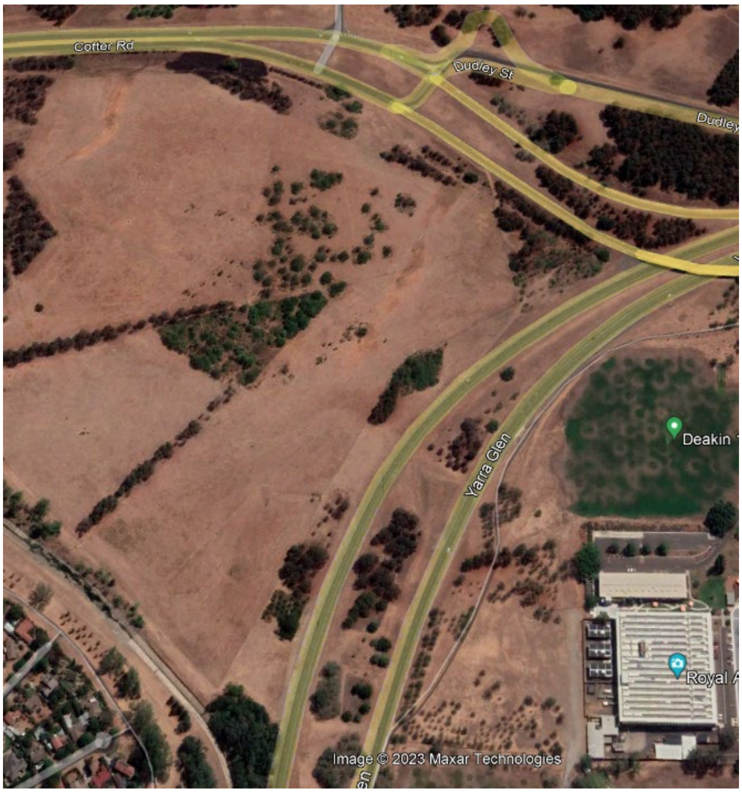


Figure 11: Site condition in Summer 2018 (baseline)

4.5 CONSTRUCTING AND SIMULATING FUTURE DESIGN SCENARIOS

To support the determination of design thresholds for 'net heat gain or loss', seven future scenarios for North Curtin were designed with varying options for UHI mitigation. These are different percentages of tree canopy cover, building materials, cool roofs, irrigated soils, wetlands, etc. See Table 8 below for a snapshot of key characteristics of FDSs.

Deloitte was provided with an indicative layout of future design of site which outlined potential use of land. The indicative layout of the site can be found in Figure 13. The site layout was processed for creating microclimate model of the site. Different tree layout and canopy cover percentage were used in different FDSs to understand the effectiveness of positioning of trees and their optimum distribution across the site.

Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16 provide map layouts of the different scenarios modelled within this assessment highlighting different tree canopy distribution and amount. Whilst the layout did not change between some of these scenarios, characteristics such as albedo, emissivity and canopy size were modified in accordance with design scenarios. See Table 8 for key differences between FDSs.

Table 8: Simulation design: key features and characteristics

Scenarios	Key characteristics	Canopy coverage of total site %	Average Canopy Diameter	Cool Roof	Cool Pavement (foot paths)	Cool Roads	Soil Irrigation	Building height	Objective
Baseline	Existing site condition								To establish a baseline microclimate of the site
FDS 1	New development with residual trees only	15%	9.8m	X	X	X	X	21m	To model the 'worst-case' scenario for the development site
FDS 2	New development with moderate size new trees	21%	7.4m	X	X	X	X	21m	To model the impact of trees 21% tree canopy cover on the microclimate of the site
FDS 4	New development with relatively larger diameter trees	35%	10.4m	√	√	√	√	21m	To understand impact of higher tree canopy cover and mixture of all heat mitigation measures.
FDS 5	FDS 4 with taller buildings	35%	10.4m	√	√	√	√	30m	Understand the impact of increasing building height
FDS 6	New tree arrangement with no cool roads	29%	8.9m	√	√	X	√	21m	To understand impact of final tree arrangement adopted in for the site by planners and the impact of not having any cool roads in the precinct
FDS 7	FDS6 with targeted vegetated roundabouts	29%	9m	√	√	X	√	21m	To understand the impact of having vegetated roundabouts in the precinct
FDS 8	FDS6 with cool roads	29%	8.9m	√	√	√	√	21m	To understand the impact of cool roads in the precinct along with other heat mitigation measures.

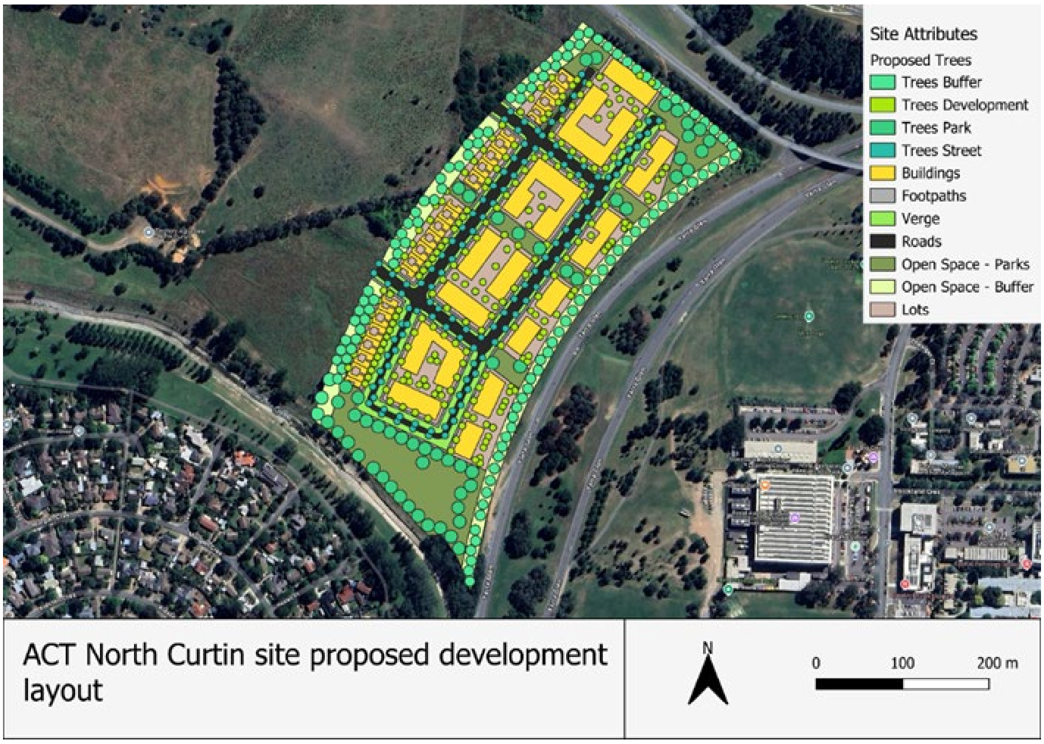


Figure 12: The North Curtin Residential Area proposed development land usage plan (client provided)

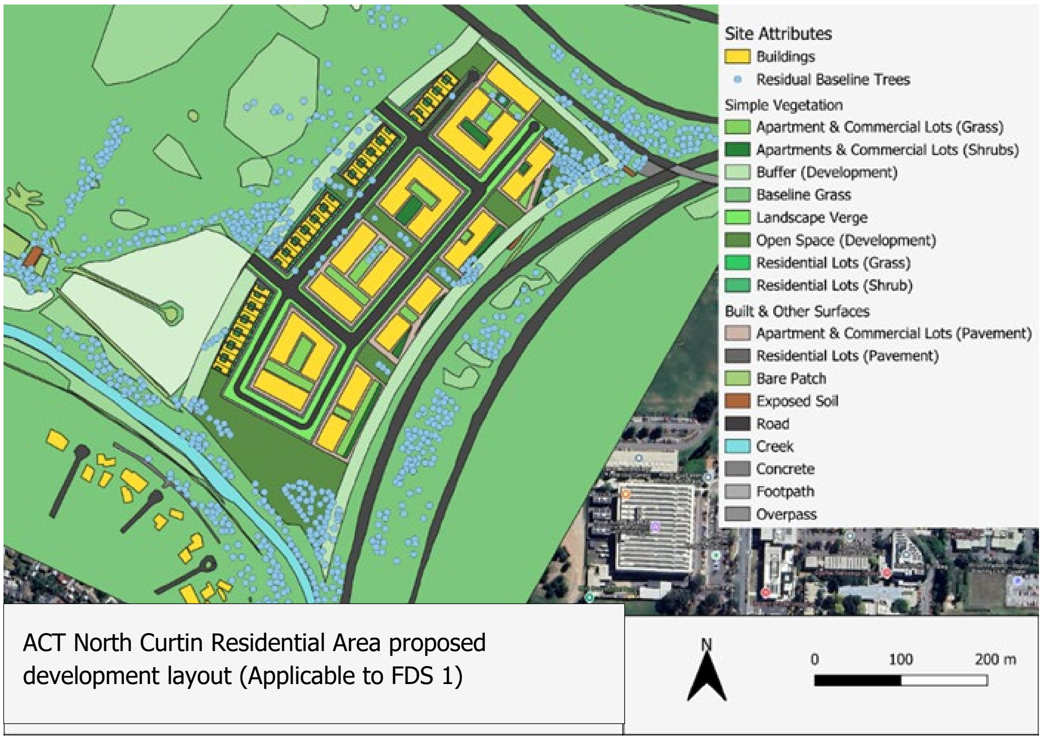


Figure 13: The North Curtin Residential Area proposed development land usage plan illustrating surrounding site condition that are included in the microclimate simulation. It has 15% tree canopy cover (FDS 1)

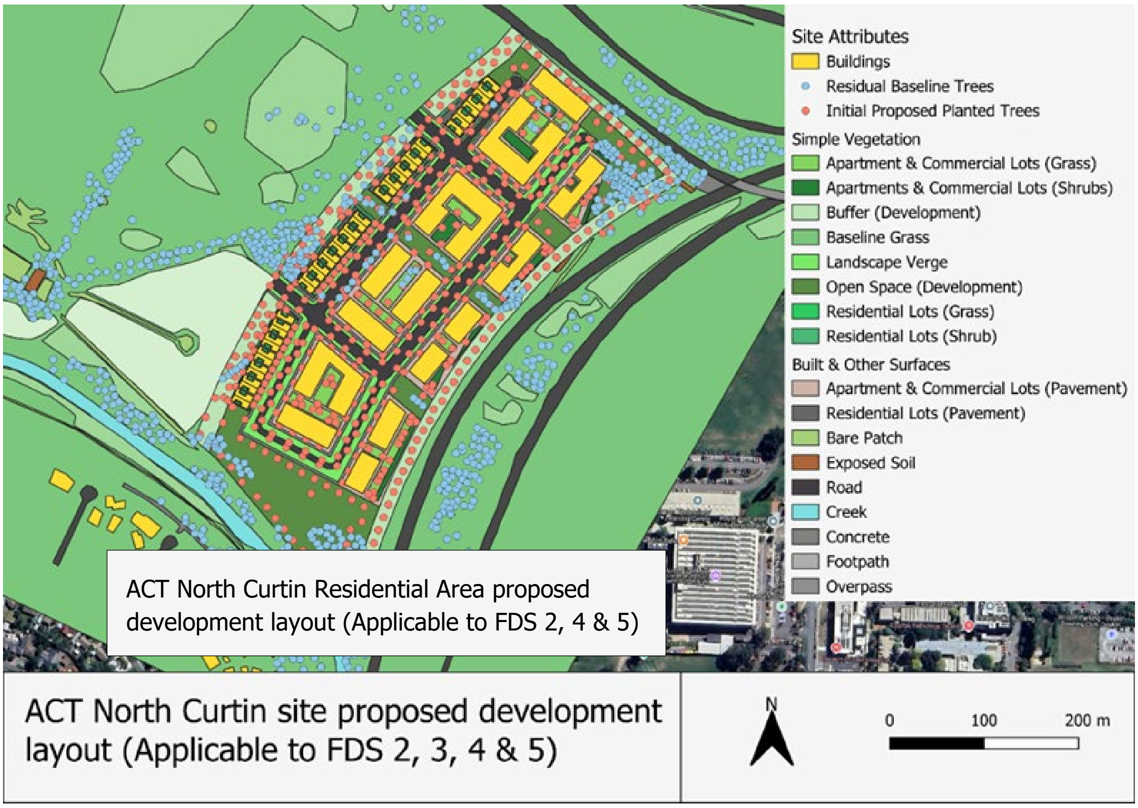


Figure 14: ACT North Curtin Residential Area proposed development land usage plan with 35% tree canopy cover (FDS 2, 4 & 5). Note: FDS-2 to FDS-5 maintain the same tree layout but differ in canopy diameter size.

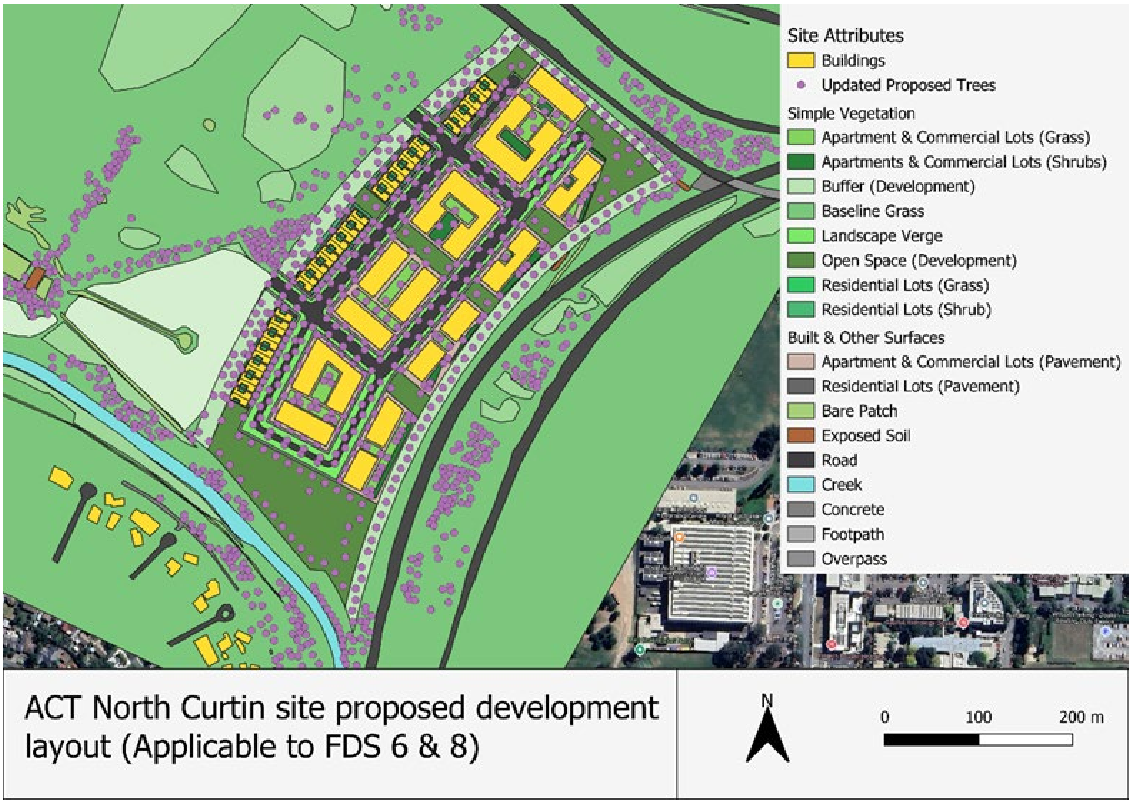


Figure 15: ACT North Curtin Residential Area proposed development land usage plan with final proposed tree layout and 27% canopy cover (FDS 6 and FDS 8)

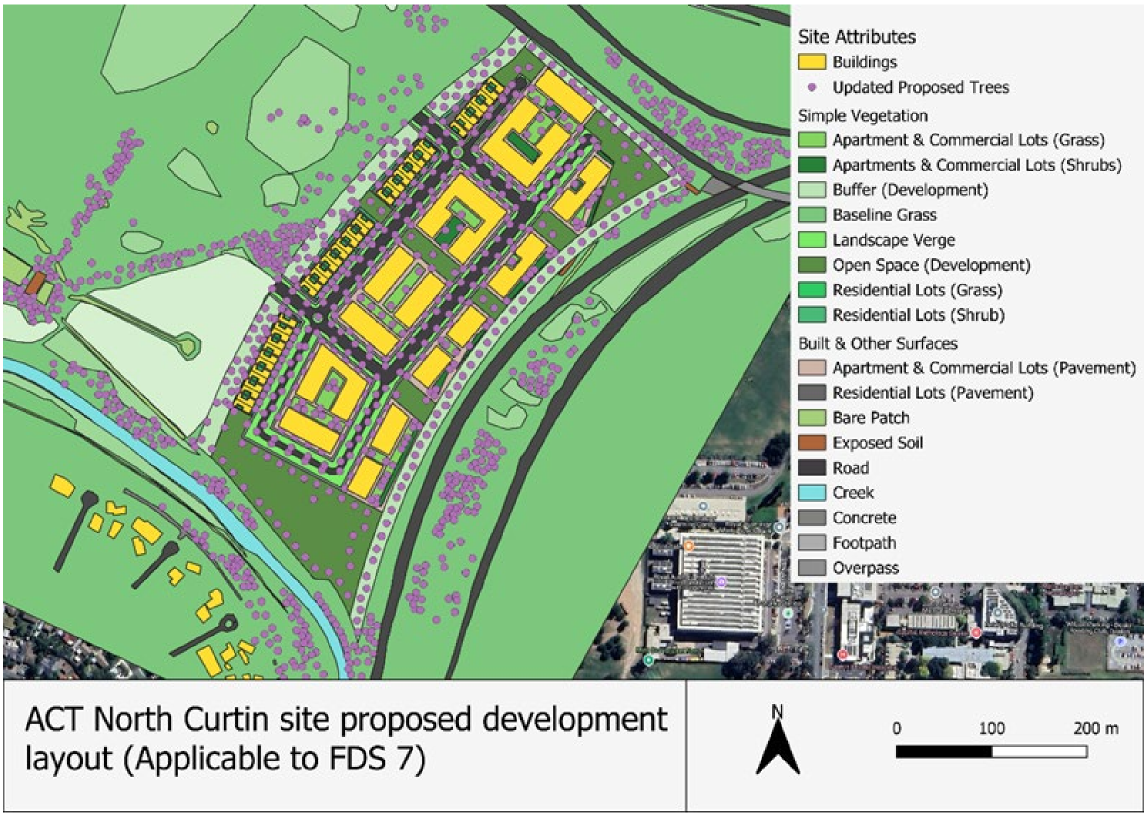


Figure 16: ACT North Curtin Residential Area proposed development land usage plan (FDS 7)

4.6 DISTRIBUTION OF LAND USE ACROSS DIFFERENT MODELLING SCENARIOS

The distribution of indicative land usage was kept consistent across all scenarios, excluding FDS 7. Table 8 below shows the percentage of each land usage type across all scenarios.

Note that only FDS 7 has slightly higher vegetation cover (53.18%) compared to rest of the scenarios, because in FDS 7 a portion of road was sacrificed to add vegetated roundabout to test its effectiveness in heat mitigation.

Table 9: Land use distribution in different microclimate simulations

<table>
<tr><th>Scenarios</th><th>Buildings</th><th>Footpath</th><th>Road</th><th>Vegetated Area</th><th>Development Lots</th></tr>
<tr><td>FDS 1</td><td rowspan="7">21.01%</td><td rowspan="7">4.54%</td><td rowspan="5">9.44%</td><td rowspan="5">52.99%</td><td rowspan="7">12.02%</td></tr>
<tr><td>FDS 2</td></tr>
<tr><td>FDS 4</td></tr>
<tr><td>FDS 5</td></tr>
<tr><td>FDS 6</td></tr>
<tr><td>FDS 7</td><td>9.24%</td><td>53.18%</td></tr>
<tr><td>FDS 8</td><td>9.44%</td><td>52.99%</td></tr>
</table>

4.7 TREE CANOPIES FOR DIFFERENT MICROCLIMATE SIMULATION SCENARIOS

The distribution of tree canopy coverage was found to be the most impactful heat mitigation strategy. Different distribution of tree canopy and their size were tested in the simulation to understand their optimum arrangement to achieve best heat mitigation effects in the North Curtin Residential Area (see Table 10 below). The guiding idea for changes was to understand what composition and layout would maximise shading and airflow, whilst keeping close to desired percentages for tree canopy coverage. For further detail and visualisation of this layout, refer to the figures in Section 4.4 (Construction of the baseline model) of this Report.

All trees used in the simulation was assumed to be matured trees. Simulation used tree species from the tree survey of the current site. Envi-met software allows assigning specific tree species and capture their water demand and evapotranspiration based on the type of the tree species making a more realistic benefit estimation of the site.

Table 10: Tree canopy coverage adopted in different FDSs.

Scenarios	Canopy coverage of total site %	Average Canopy Diameter
FDS 1	15%	9.8m
FDS 2	21%	7.4m
FDS 4	35%	10.4m
FDS 5	35%	10.4m
FDS 6	27%	8.9m
FDS 7	28%	9m
FDS 8	27%	8.9m

4.8 WATER SENSITIVE URBAN DESIGN

For scenarios where irrigated soil was used 39% of total vegetated areas were irrigated, equating to 21% of the total site. Note, irrigated soil for the purposes of this assessment refers to any method which ensures specified areas receive regular watering. For example, some methods could include rainwater harvesting (rain gardens), wetlands, sprinkler irrigation, and subsurface irrigation. Figure 17 illustrates which simple vegetation areas were modelled as irrigated (light blue); these areas are all classified as open spaces.

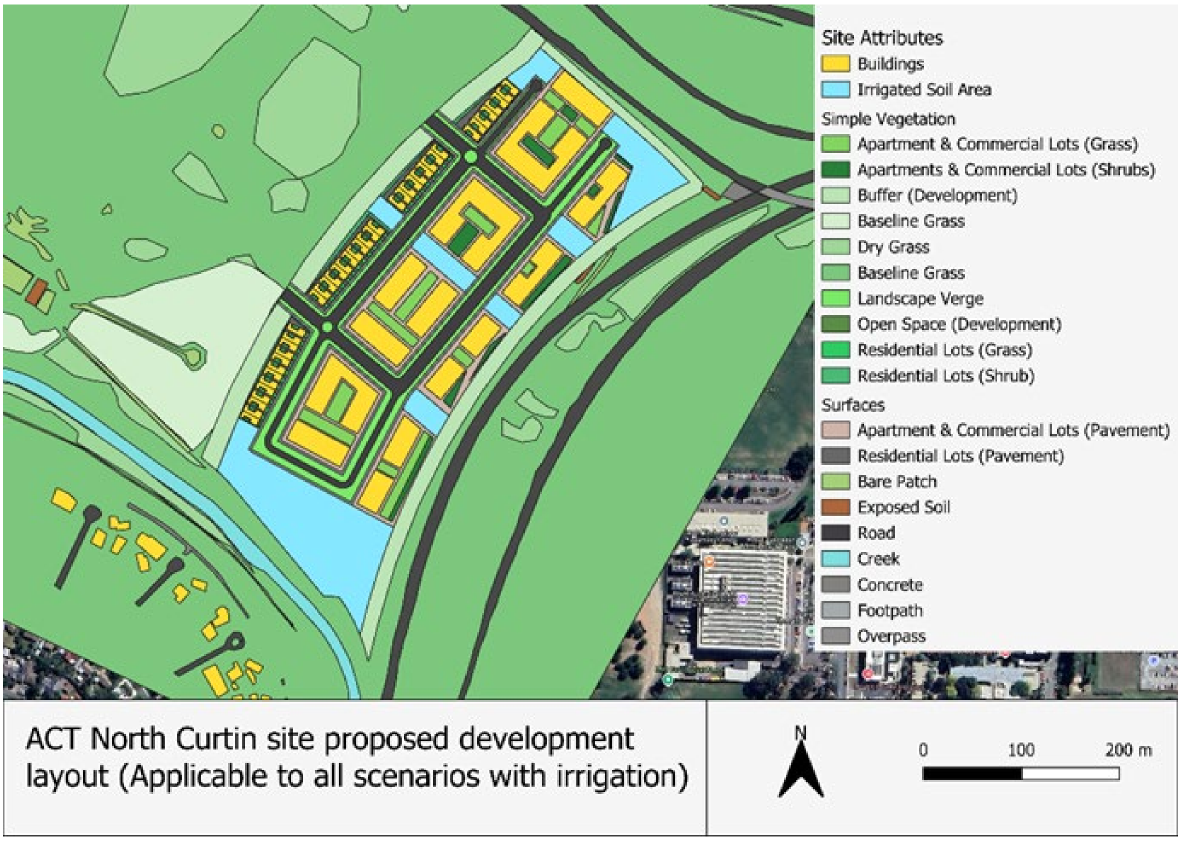


Figure 17: ACT North Curtin Residential Area proposed development layout with highlights of irrigated soil areas (light blue)

4.9 MATERIAL CHARACTERISTICS OF FUTURE DESIGN SCENARIOS

Albedo and emissivity are the key variation of material characteristics between different future design scenarios. Table 17 in Appendix A shows building materials and surface types which are used in all future design scenarios, as well as their albedo and emissivity values.

Table 11 below shows how the albedo and emissivity values change for building materials and different surfaces across all scenarios. Albedo and emissivity are sourced from published documents and commercial product catalogue (Dulux, 2020; Haddad et al., 2020).

Table 11: Changes in reflectivity (albedo) of key built environment features across different scenarios.

Material	FDS 1	FDS 2	FDS 4	FDS 5	FDS 6	FDS 7	FDS 8
Asphalt Road	Low	Low	High	High	Low	Low	High
Concrete Pavement	Low	Low	High	High	High	High	High
Concrete Roof	Low	Low	High	High	High	High	High
Tiling Roof	Low	Low	High	High	High	High	High
Wall	Low	Low	High	High	High	High	High

5 RESULTS AND DISCUSSION

5.1 OVERVIEW

This section provides the results and analysis of the microclimate scenario assessment conducted for the North Curtin Residential Area. The section provides detailed discussion on the following with regards to the microclimate model scenarios:

1. A comparison between baseline and the development models
2. Air temperature
3. Surface temperature
4. Mean radiant temperature
5. Observed impacts of heat management strategies, and
6. The final findings.

It is recommended the reader refer also to Appendix B for the spatial maps developed as part of the microclimate assessment. The spatial maps provide visualisations of the potential air temperature, surface temperature, and mean radiation temperature of all the modelled scenarios.

5.2 COMPARISON BETWEEN BASELINE AND DEVELOPMENT MODELS

Table 12 and Table 13 below provide a summary of simulation results from the microclimate assessment, across different modelling scenarios.

Table 12 presents the daily average of air, surface, and radiant temperature while Table 13 presents same variables across different time of the day. All figures in the table are measured in degrees Celsius (°C). Green indicates that the temperature achieved in the FDS is below the baseline model ('net heat loss'), while red indicates that the temperature of FDS is above baseline ('net heat gain'). Orange signifies that a result was slightly over the baseline and possibly within a margin of error for the modelling.

The results show that when daily average temperature is compared, FDS 4, FDS 5 and FDS 8 all achieved 'net heat losses' compared to the baseline. On the other hand, FDS 6 and FDS 7 both are 0.04°C more than the baseline which is considered to be within the margin of error of microclimate simulation modelling, therefore can be considered as 'neutral in terms of heat gain or loss' (i.e., similar thermal performance compared to the baseline).

Table 12: Comparison of daily average temperature indices between baseline and different FDSs

Scenarios	Key characteristics	Canopy coverage of total site %	Average Canopy Diameter	Cool Roof	Cool Pavement (foot paths)	Cool Roads	Soil Irrigation	Maximum Building height	Daily Average Potential Air Temperature (°C)	Daily Average Surface Temperature (°C)	Daily Average TMRT (°C)
Baseline	Existing site condition								28.7	24.2	27.8
FDS 1	New development with residual trees only	15%	9.8m	X	X	X	X	21m	29.0	24.6	28.2
FDS 2	New development with moderate size new tress	21%	7.4m	X	X	X	X	21m	28.9	24.1	27.2
FDS 4	New development with relatively larger diameter trees	35%	10.4m	√	√	√	√	21m	28.5	22.8	26.0
FDS 5	FDS 4 with taller buildings	35%	10.4m	√	√	√	√	30m	28.5	23.2	25.0
FDS 6	Final tree arrangement adopted by planners with no cool roads	29%	8.9m	√	√	X	√	21m	28.7	22.8	25.9
FDS 7	FDS6 with targeted vegetated roundabouts	29%	9m	√	√	X	√	21m	28.7	22.9	26.1
FDS 8	FDS 6 with cool roads	29%	8.9m	√	√	√	√	21m	28.6	22.5	26.2

Table 13: Comparison of temperature indices at different time of the day

Microclimate Scenario	Description	Mid-morning (9am)			Early afternoon (12pm)			Mid-afternoon (3pm)			Late Evening (9pm)		
		Air Temp at 1.5m (°C)	Surface Temp (°C)	Mean Radiant Temp (°C)	Air Temp at 1.5m (°C)	Surface Temp (°C)	Mean Radiant Temp (°C)	Air Temp at 1.5m (°C)	Surface Temp (°C)	Mean Radiant Temp (°C)	Air Temp at 1.5m (°C)	Surface Temp (°C)	Mean Radiant Temp (°C)
Baseline Model	Present day site arrangement (building materials, road surface, trees, and vegetation)	23.2	19.3	13.6	29.7	22.6	19.7	32.3	24.7	21.6	29.2	29.4	50.5
FDS 1	No additional trees beyond baseline trees, and no mitigation measures	23.6	19.3	14.2	29.8	22.2	19.9	32.5	25.1	22.1	30.1	31.7	56.5
FDS 2	Moderate tree coverage (residual and client design trees), with no other mitigation measures.	23.6	19.2	14.2	29.8	22.0	19.7	32.4	24.9	22.1	29.7	30.3	52.8
FDS 4	High vegetation coverage (residual trees, and client design trees with increased canopy size), high material reflectivity (roofs, walls, roads, and pavement), irrigated soil, and 21m max building height	23.3	18.9	14.0	29.6	21.0	19.1	32.2	24.5	21.6	29.1	27.0	49.2
FDS 5	Similar to FDS 4, with max building height increased to 30m	23.3	19.0	14.1	29.6	21.4	19.1	32.2	24.4	21.7	29.1	28.1	45.4
FDS 6	Revised tree canopy coverage (no residual trees included), with moderate material reflectivity (roofs, walls, and pavement)	23.4	19.0	14.3	29.7	21.4	19.4	32.3	23.2	21.3	29.3	27.6	48.4
FDS 7	Similar to FDS 6, with modifications made to include trees at road intersections (hotspots)	23.4	18.9	14.1	29.7	21.3	19.4	32.3	23.1	21.2	29.4	28.1	49.7
FDS 8	Similar to FDS 6, but with high reflectivity roads	23.4	19.0	14.3	29.7	21.4	19.4	32.3	23.2	21.3	29.1	26.4	49.8

Below Baseline   0.2 within Baseline   Above Baseline

5.3 KEY OBSERVATIONS

The results show that when daily average temperature is compared, FDS 4, FDS 5 and FDS 8 all achieved 'net heat-losses' compared to the baseline. On the other hand, FDS 6 and FDS 7 both are 0.04°C more than the baseline which is considered to be within the margin of error of microclimate simulation modelling, therefore can be considered as 'neutral in terms of heat gain or loss' (i.e., similar thermal performance compared to the baseline). When observing the results throughout the day, the following observations can be made.

From daily average temperature point of view, the best performing scenarios were FDS 4 and FDS 5 across all three indicators (air, surface, and radiant temperature). This is partly due to the highest tree canopy cover (35%) in those scenarios. Among the three scenarios that used final adopted site and tree layout (prepared by the ACT Government appointed Planners), FDS 8 performed the best noting very small temperature differences between these three FDSs.

Wind direction and its ability to flow through the buildings to allow for effective heat transfer as well as sun path play a crucial role in determining potential air temperature of the future design simulations of the North Curtin Residential Area. The below table summarises key findings from each model with regards to air temperature.

Simulation maps for different FDSs illustrating air temperature variabilities are presented in Appendix B.

Table 14: Key observations across different FDSs

Model	Key findings
Baseline model	• Cool spots are consistently observed in areas with trees and vegetation throughout the day. The cooling effect is particularly pronounced in areas with concentrated tree coverage. The cooling effect provided by the trees is most noticeable at 9am and 9pm. • At 12pm and 3pm, the air temperature tends to be higher in the northern parts of the site.
FDS 1	• Reduction in 9pm cool spots in comparison to baseline. This is likely due to wind flow being blocked by the buildings and the removal of most baseline trees.
FDS 2	• FDS 2 failed at achieving air temperature at or below baseline throughout the day. This is likely due to low tree coverage and no other mitigation measures being implemented.
FDS 4	• All thermal indices improved in FDS 4 compared to FDS 2 as different heat mitigation measures such as increased tree canopy (35%), cool roof, cool road and areas of irrigated soil are introduced. • One notable aspect is that during the hottest period of the day (at 3pm), air, surface and mean radiant temperature are below baseline.
FDS 5	• Multi-storied building heights in FDS 5 were increased to 30m to understand sensitivity of building height in precinct temperature. Overall, the surface temperatures in FDS 5 were slightly hotter in different timeframes throughout the day when compared to FDS 4 surface temperatures (e.g., 0.1°C hotter). This is partly due to presence of some additional thermal mass in the precinct due to increased building height. However, when FDS 4 and FDS 5 are compared with the baseline, both performed similarly throughout the day across all indices with the exception of slightly higher surface temperature at the hottest time of the day (3pm). However, this difference between baseline and FDS 5 at 3pm is only 0.1°C, which is within the model error range.
FDS 6	• FDS 6 adopted the final indicative site and tree layout developed by the Planners for the North Curtin Residential Area. It has 27% tree canopy coverage and other heat mitigation measures included (e.g., cool roof, irrigated soil areas, and cool pavements). Cool roads were not included in this scenario.

	• Due to the removal of cool roads and slight reduction in tree canopy (compared to FDS 5), FDS 6 was slightly hotter throughout the day when compared to FDS 5. However, when compared to the baseline, FDS 6 performed better when daily average of indices is compared. • Except for mean radiant temperature at early morning 9am, FDS 6 performed better compared to baseline in all timeframes. This is potentially due to the east-facing layout of the site which is rapidly heating the precinct compared to baseline in the morning. As the day progresses, wind flow allows heat to move around and transfer resulting in better performance in the later part of the day.
FDS 7	• Similar results to FDS 6, but with slight cooling in the intersections at locations roundabouts were placed with a tree.
FDS 8	• In FDS 8, cool roads were added to understand its effectiveness in the North Curtin Residential Area. • In general, FDS 8 performed better compared to baseline, FDS 6 and FDS 7 as expected as it had all heat mitigation measures embedded (28% tree canopy, cool roof, cool pavement, cool road, and irrigated soil). However, it is noted that the extent of improvement compared to FDS 6 is very small.

5.4 ADDITIONAL ANALYSIS AND COMPARISON

Air temperature was the primary indicator used in this assessment which was discussed in detail in Table 14. Surface temperature and mean radiant temperature are two additional indicators of heat gain or loss which was investigated in this study.

Table 15 and Table 16 summarises key findings from each model with regards to surface temperature and radiant temperature respectively.

Table 15: Comparison of the surface temperature between the models

Model	Key findings
General observations	• From 9am to 9pm, FDS 4 to FDS 8 consistently achieved surface temperatures that were at or below the baseline model. Tree and vegetation cover provides the most significant cooling across all modelled scenarios.
Baseline model	• At 9pm, all areas exposed to sunlight throughout the day have reached their peak surface temperature. The only areas showing any signs of cooling are those under shade, particularly the shade provided by trees.
FDS 1	• The model indicates that throughout the day, surface temperature increases as areas become more exposed for longer periods of time to direct sunlight (i.e., North to South roads). Shading provide by trees and buildings appears to be the most efficient cooling strategies. • At 9pm, all areas exposed to sunlight throughout the day have reached their peak surface temperature. The only areas showing any signs of cooling are those under shade, particularly the shade provided by trees.
FDS 2	• FDS 2 failed at achieving a surface temperature below baseline at 9pm. The results were similar to that of FDS 1, with changes being driven by additional canopy coverage.
FDS 4	• The introduction of highly reflective roads appears to effectively reduce surface temperature. This is particularly evident at 9pm, which illustrates that the roads appear cooler than in previous scenarios.
FDS 5	• Whilst still achieving a surface temperature below baseline across all timeframes, FDS 5 ran slightly hotter than FDS 4 despite having all the same conditions except building height. This

	suggests that increasing building height can lead to slight hotter temperatures, particularly at night, likely due to the increase in built surfaces radiating heat. However, this increase in temperature in simulation result is very low (around 0.1°C).
FDS 6	• FDS 6 show substantial cooling of surface temperatures in irrigated areas, vegetated areas and areas shaded by buildings. This cooling translated to a successful pass of 'net-zero' heat gain across all timeframes.
FDS 7	• FDS 7 showed similar results to FDS 6, but with additional cooling in the intersections due to the addition of roundabouts with large trees.
FDS 8	• FDS 8 had noticeably cooler roads compared to FDS 6 and FDS 7 at the 9pm timeframe. This can be attributed to the high reflective material used.

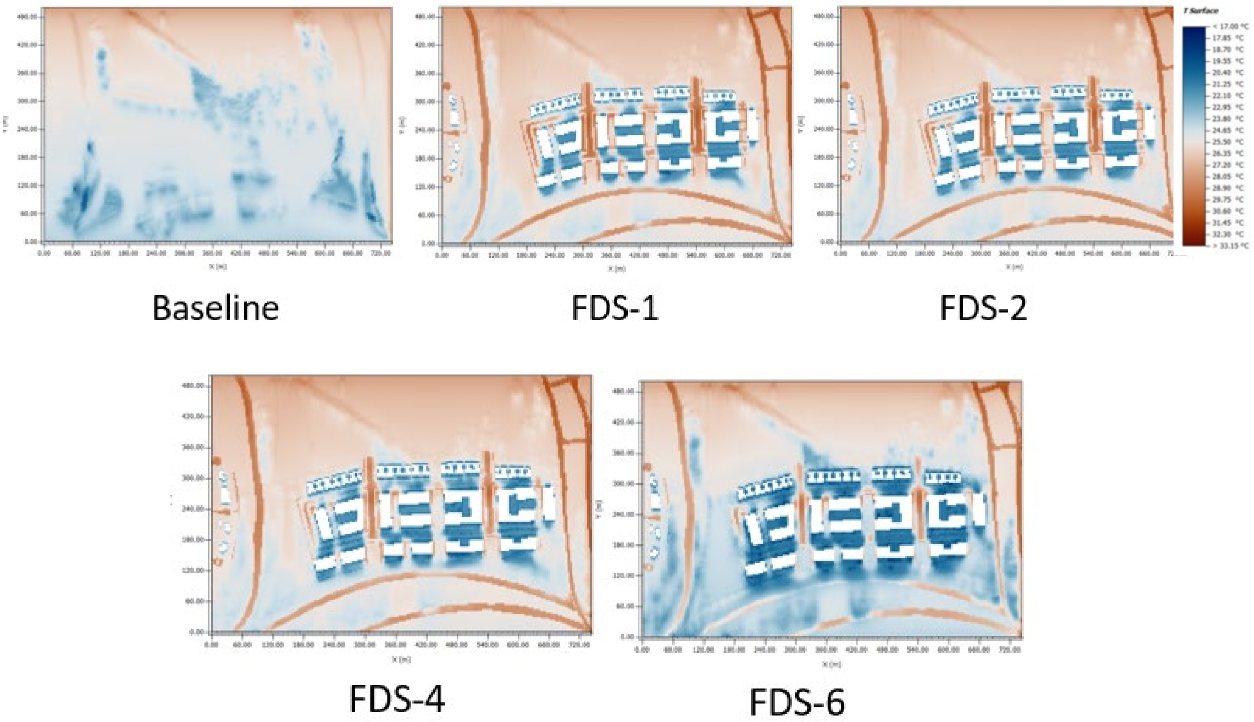


Figure 18: Comparison of surface temperature at 3pm across different FDSs and baseline

By introducing different heat mitigation measures in the FDSs progressively allows achieving improved surface temperature. For example, FDS 1 has only 15% tree canopy cover and does not have any additional heat mitigation measures. On the other hand, FDS 6 has 29% tree canopy cover, and additional heat mitigation measures such as cool roof, cool pavements, irrigated soil areas which resulted in improved surface temperature (see Figure 18). By adding cool roads in the models (e.g., FDS 8), improvement in surface temperature was achieved. This is more pronounced at night (see Figure 22).

Table 16: Comparison of the mean radiant temperature between the models

Model	Key findings
Baseline model	• At 9am, the baseline model shows a uniformly cool mean radiant temperature, with minimal variation visible on the heat map. By 12pm and 3pm, the cooling effect is most noticeable in areas covered by trees and vegetation. However, at 9pm, the mean temperature is highest in regions lacking tree and vegetation coverage. This indicates that while there is limited variation in mean radiant temperature at midday and mid-afternoon, significant changes are observed in the early morning and late evening.
FDS 1	• During all times of the day, the heat maps indicate temperatures above the baseline model. The most significant increase is observed at 9pm, as the mean temperature modelled for the scenario was 6ºC above baseline. The heat maps indicate that the only cool spots at this time are where trees sides of the buildings are located. • At 3pm, the cooling effect of trees appear to decrease, in comparison to 12pm.
FDS 2	• FDS 2 failed to achieve TMRT below baseline at both 9am and 12pm. The heat maps indicate this result can likely be attributed to a lower canopy coverage and lack of highly reflective material.
FDS 4	• FDS 4 was successful at achieving a TMRT below baseline across all timeframes except 9am (like all other scenarios) but came the closest (0.4°C) to the baseline. • Heat maps suggest vegetation had the greatest role in reducing TMRT.
FDS 5	• Similar to FDS 4, FDS 5 was successful at achieving a TMRT below baseline across all timeframes, except at 9am. However, there were some noticeable differences, such as 9pm, where FDS 5 recorded the lowest TMRT across all scenarios. The heat maps depict slightly more pronounced cooling around the buildings in FDS 5 when compared to FDS 4 at the 9pm timeframe. This suggests the increased shading from a greater building height may have had some role.
FDS 6	• FDS 6 show substantial cooling of TMRT in irrigated areas, vegetated areas and areas shaded by buildings at the 9pm timeframe.
FDS 7	• FDS 7 showed similar results to FDS-6, but with additional cooling in the intersections due to the addition of roundabouts with large trees.
FDS 8	• FDS 8 had noticeably cooler roads compared to FDS 6 and FDS 7 at the 9pm timeframe. This can be attributed to the high reflective material used.

5.5 EFFECTIVENESS OF DIFFERENT HEAT MITIGATION STRATEGIES

As previously mentioned in this Report, the heat mitigation strategies deployed in modelling for the North Curtin Residential Area include variation of canopy coverage and layout, adjustments to material reflectivity, and irrigation of soil. This section will discuss the differing levels of impact for each of these heat mitigation strategies. However, it is important to note that despite different levels of effectiveness a combination of all strategies is required to achieve a 'net-zero' heat gain for the site.

5.5.1 VEGETATION COVERAGE AND LAYOUT

Modelling found that vegetation had the most significant impact in reducing heat within the site across all three metrics (potential air temperature (°C), surface temperature (°C), and TMRT). This is clearly seen below in Figure 19, which shows the absolute difference in surface temperature between FDS 1 which had only a minimal number of trees and FDS 6, which along with FDS 7 and FDS 8, had the greatest quantity of trees and second highest canopy coverage extent for vegetated areas.

The left hand map at Figure 19 below depicts FDS 6 having substantially cooler surfaces across most of the site, except for areas where FDS 1 had a high concentration of residual baseline trees which were removed in the later scenarios (this was done to align with the indicative site layout that is adopted by Planners). A similar trend is also observed for potential air temperature and TMRT (right hand side map and bottom map respectively). TMRT result specifically illustrates that the areas with trees have better thermal comfort which indicates that careful consideration should be paid towards the layout of trees to ensure thermal comfort in 'live-in spaces' (i.e., areas between multi storied buildings).

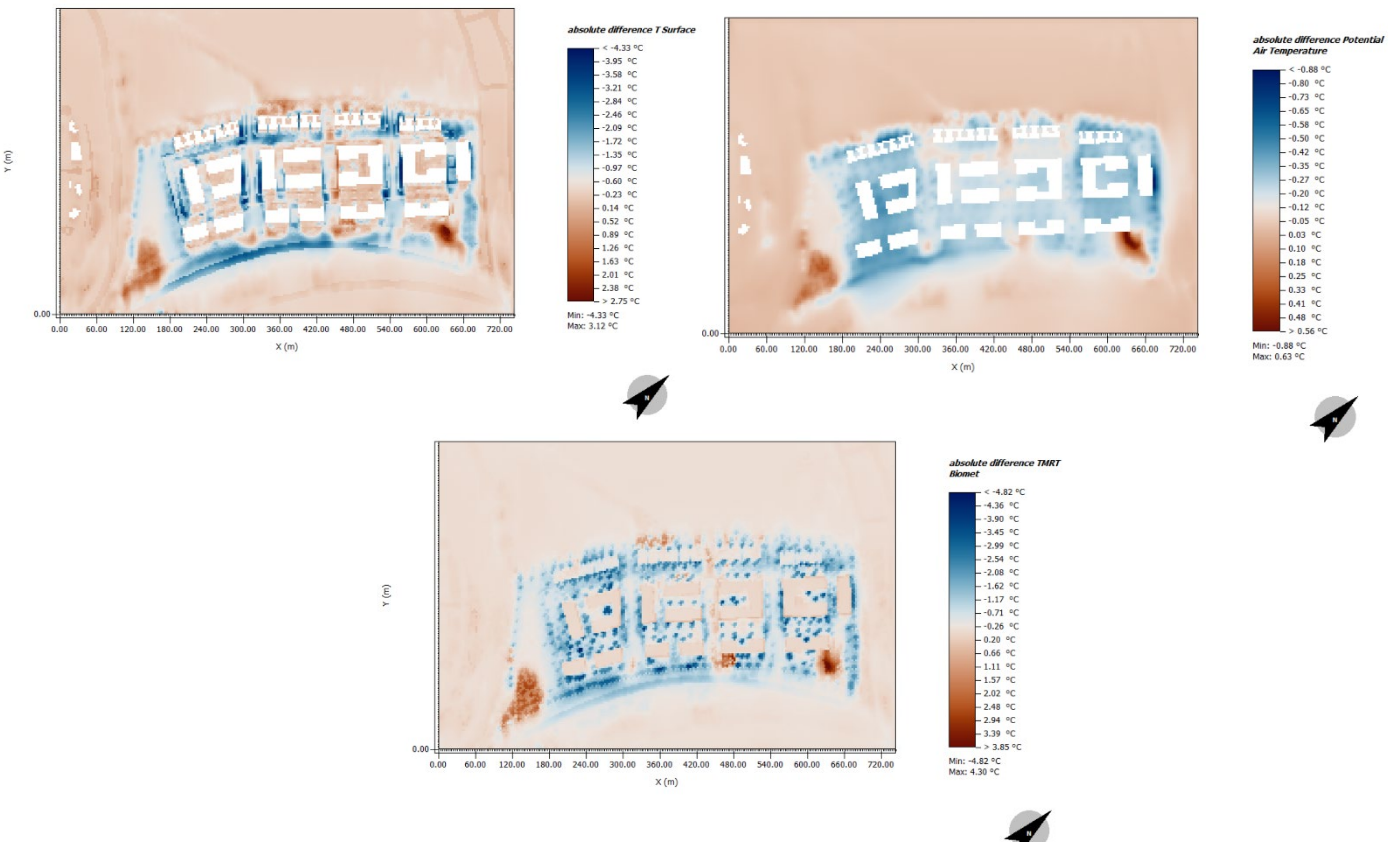


Figure 19: Heat maps illustrating difference of temperature between FDS 1 and FDS 6 at 12pm. Blue areas suggest that FDS 6 is cooler compared to FDS 1 where brown areas suggest that FDS 6 is hotter compared to FDS 1. Top left map illustrates air temperature at 1.5m, top right shows surface temperature and bottom map shows mean radiant temperature.

5.5.2 IRRIGATION OF SOIL

The irrigation of soil was found to be effective in reducing temperature across all three metrics measured. This can be seen in Figure 20 and Figure 21, which compares the surface temperatures of FDS 1 and FDS 7 at night (9pm) and day (12pm) respectively, showing the impact of irrigated soils, including through the use of raingardens or wetlands on surface temperature at 9pm.

In Figure 20, the map on the left is FDS 1 with no irrigated soils, and the map on the right is FDS 7 with some of the green areas assumed as irrigated land. For example, area marked in yellow dotted line is assumed in FDS 7 as irrigated resulting in relatively lower surface temperature in that portion of the precinct compared to FDS 1.

In the comparative heatmap (Figure 21), the open area located on the left-side (largest irrigated zone) was hotter under FDS 1. In the same figure it can also be seen how other heat mitigation elements like vegetation coverage and layout, as well as highly reflective roads and pavement also led to a reduction in heat. It is critical to emphasise that raingardens, wetlands, or irrigation of vegetated areas, are still necessary to achieve a 'net-zero' heat gain under FDS 7.

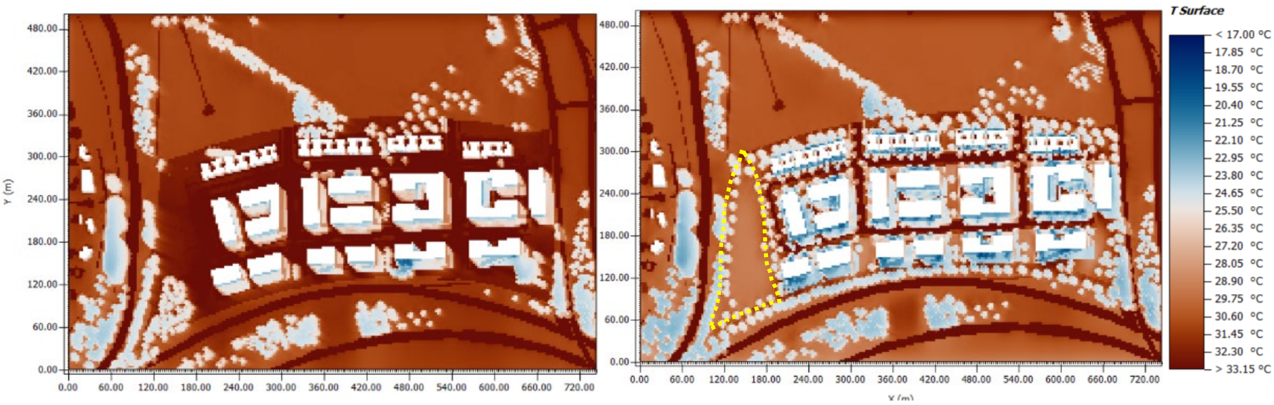


Figure 20: Impact of raingardens, wetlands, and irrigation on surface temperature at 9pm. Left hand side is FDS 1 with no raingarden and irrigation and right-hand side is FDS 7 with some of the vegetated areas assumed as irrigated land. For example, area under yellow dotted line is assumed as irrigated land in the simulation resulting in lower surface temperature.

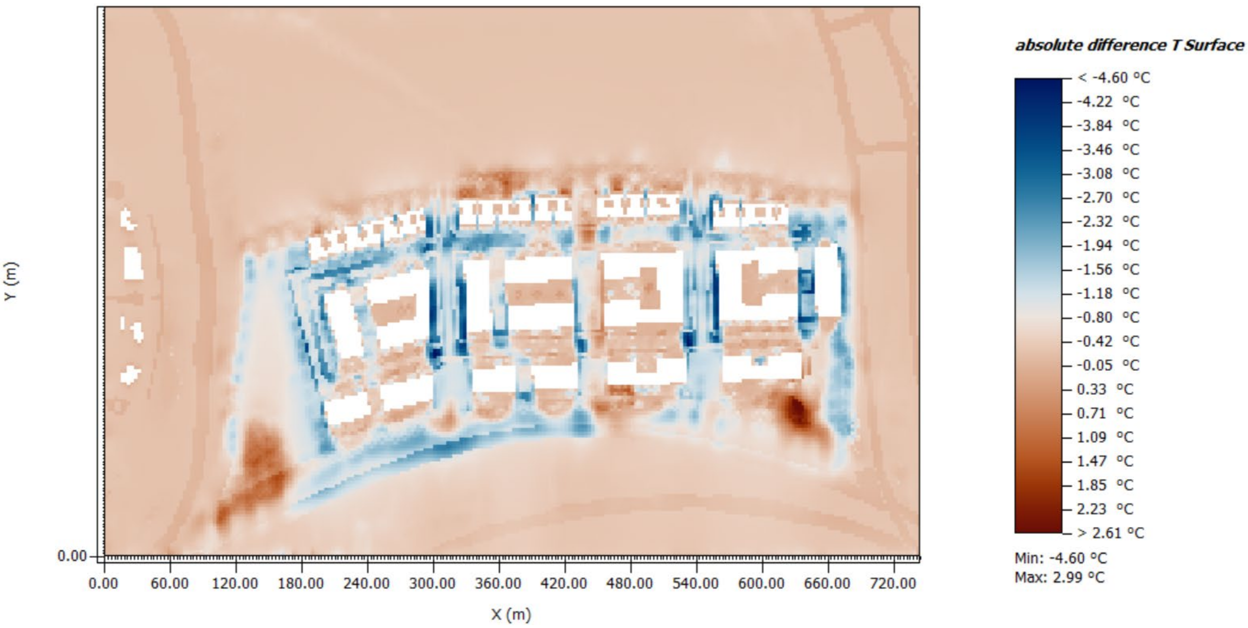


Figure 21: Difference in surface temperature during the day (12pm) between FDS-1 (no rain gardens) vs FDS 7 (with raingardens in targeted areas). Blue marked areas suggest a reduction in surface temperature in FDS 7.

5.5.3 BUILDING HEIGHT ADJUSTMENTS

For all scenarios but FDS 5, the maximum building height was 21m. The results for FDS 4 and FDS 5 suggest there is minimal impact on average site temperature when increasing the building height (assuming all other variables remain constant). Multi-storied building heights in FDS 5 were increased to 30m to understand sensitivity of building height in precinct temperature. Overall surface temperatures in FDS 5 were slightly hotter in different timeframes throughout the day when compared to FDS 4 surface temperatures (e.g., 0.1°C hotter). This is partly due to presence of some additional thermal mass in the precinct due to increased building height. However, when FDS 4 and FDS 5 are compared with the baseline, both performed similarly throughout the day across all indices with the exception of slightly higher surface temperature at the hottest time of the day (3pm). However, this difference between baseline and FDS 5 at 3pm is only 0.1°C which is within the model error range. Discrepancies between the two scenarios can be attributed to changes in wind flow and shading, as well as model variation.

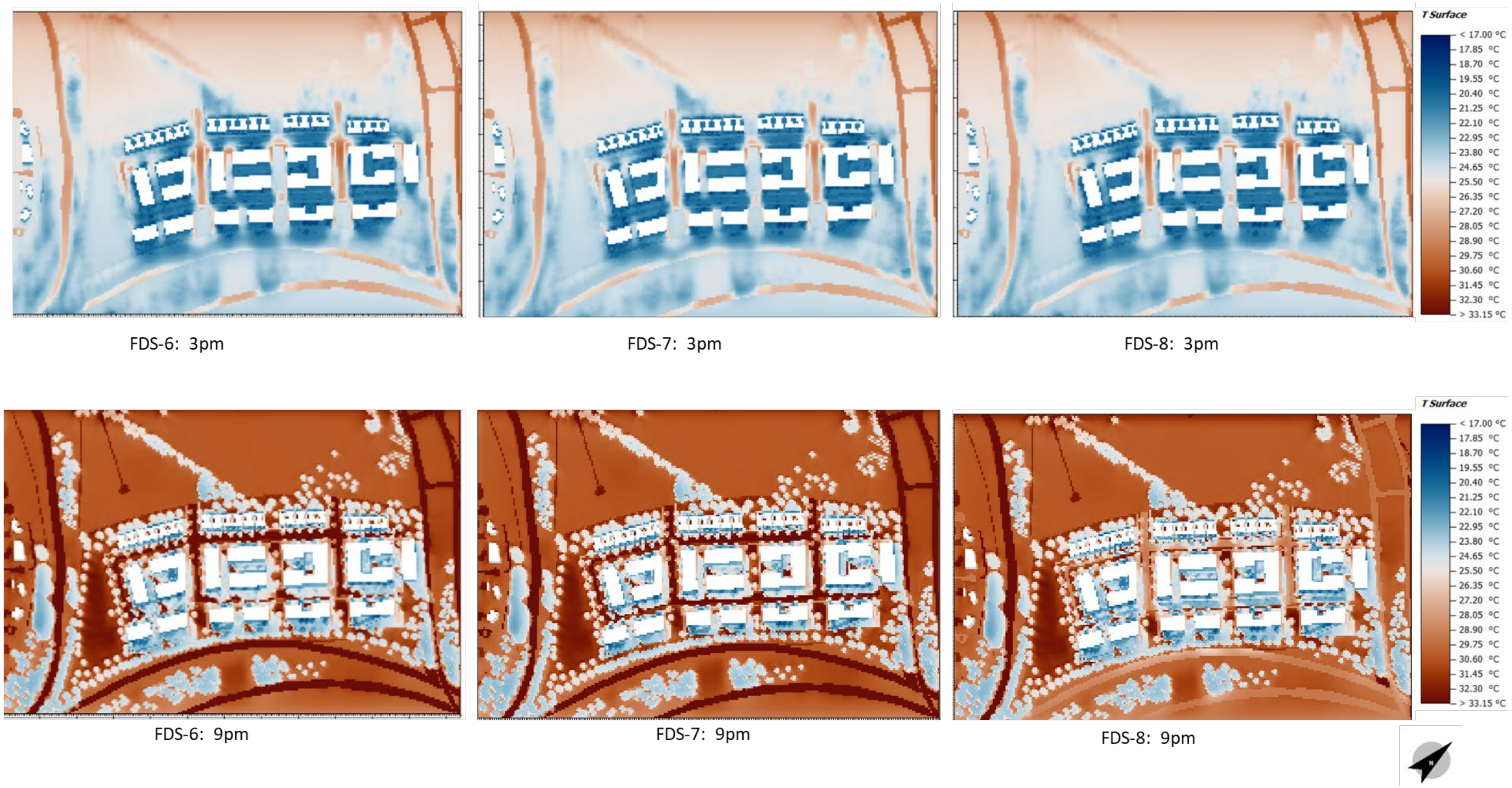
5.5.4 MATERIAL REFLECTIVITY

Material reflectivity was most impactful in areas with minimal shading, particularly roads. Given the wide extent of vegetation coverage currently planned for the site, the overall impact of highly reflective material on average temperatures is marginal. This is perhaps best understood when comparing FDS 6 with FDS 8, both of which had exact same building layout, tree canopy and levels of irrigated soils, with the exception of FDS 8 which had cool road added to the simulation. Figure 22 shows the surface temperature at 3pm and at 9pm across FDS 6, FDS 7 and FDS 8. It is clear that FDS 8 with cool road has a relatively lower surface temperature which is more pronounced at night. This is because cool road absorbs less heat throughout the day therefore release less heat at night compared to standard roads. However, it is noted that the extent of improvement in FDS 8 compared to FDS 6 is very small.

5.5.5 BUILDING LAYOUT AND WIND FLOW

Wind direction and flow play a crucial role in determining heat condition in a given precinct. In urban precincts, wind flow and building layout are critical factors for effective heat management, impacting both outdoor comfort and energy efficiency. Properly designed layouts can enhance natural ventilation, reducing the accumulation of heat between buildings and promoting cooling effects. Open spaces, wide streets, and varied building heights help to channel breezes, dissipating heat from surfaces and improving thermal comfort for pedestrians. When buildings are densely packed, they can create a ‘canyon effect’, trapping warm air and limiting airflow, which intensifies the UHI effect. Orienting buildings to capture prevailing winds and incorporating ventilated corridors allow cooler air to circulate freely, mitigating heat buildup. Moreover, allowing air to flow through courtyards or green spaces can help cool the air before it enters buildings, reducing the need for artificial cooling.

Figure 23 shows wind flow direction and air temperature under FDS 6 simulation. The wind vector map shows that a ‘canyon effect’ in between multistoried buildings with slightly elevated temperature compared to surrounding areas. This can be avoided by potentailly making slight adjustment in the building layout allowing wind to pass freely from north-west to south-east side of the precinct. North-west to south-east is the dominant wind flow direction of the site as per the Bureau wind rose (see Appendix A), therefore this adjustment can help better wind flow across the precinct. In general, having irrigated grass in the courtyard of a high-rise complex offers enhanced environmental, social, and aesthetic benefits compared to setback areas. Courtyards provide centralised green spaces that are more accessible and visible to residents, promoting outdoor activities and social interaction. The grass helps regulate temperatures by reducing heat absorption, creating a cooler microclimate in densely urbanised areas which was observed in the North Curtin Residential Area simulation. Conversely, grass in setback areas is less utilised, often serving as passive green zones.



FDS-6: 3pm FDS-7: 3pm FDS-8: 3pm

FDS-6: 9pm FDS-7: 9pm FDS-8: 9pm

Figure 22: Surface temperature across three FDSs with adopted site layout by planners. Top three images show surface temperature at 3pm and bottom three images show surface temperature at 9pm across three FDSs.

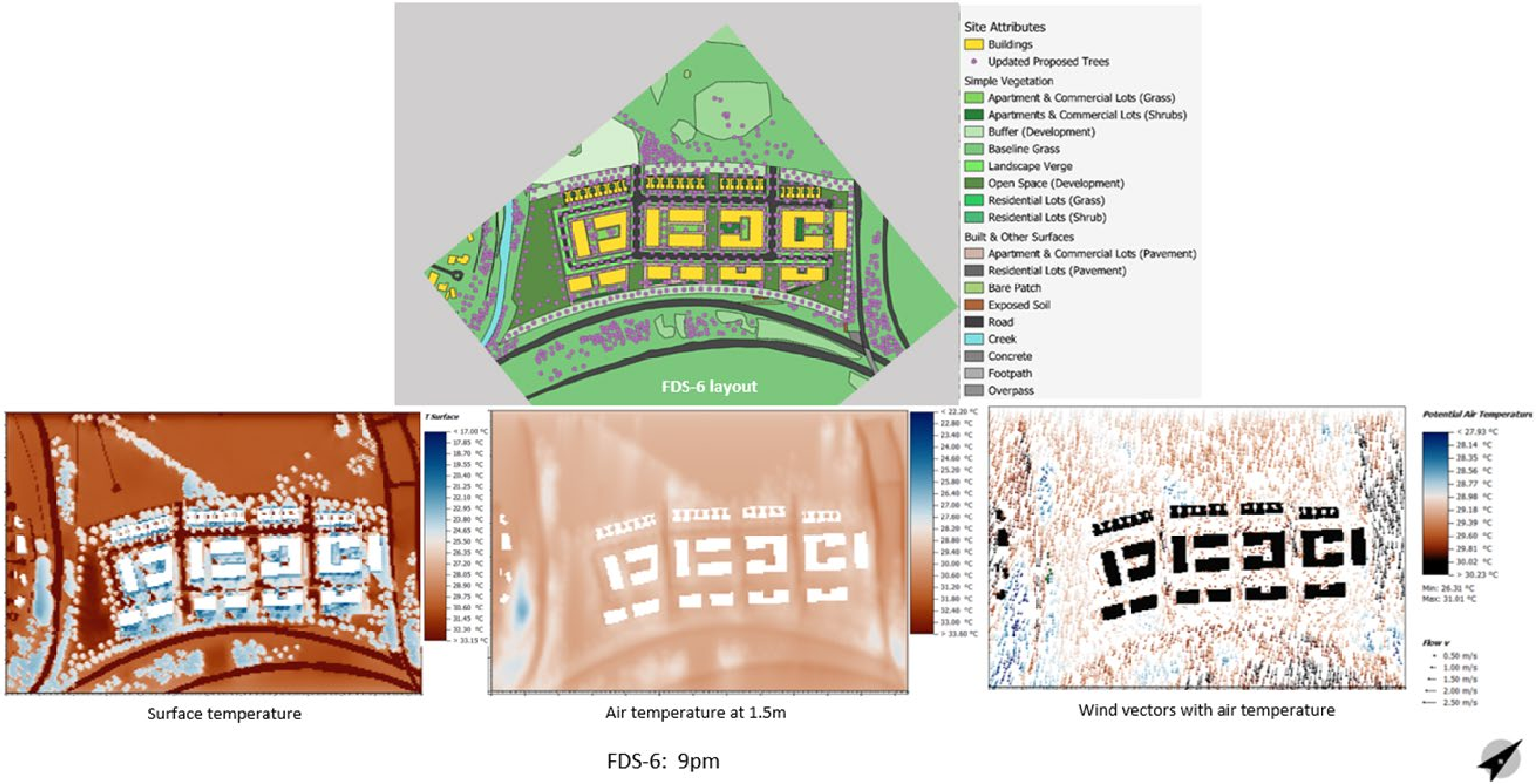


Figure 23: FDS 6 site layout (top), surface temperature (left), air temperature (middle) and wind vectors (right) at 9pm at night. Wind vector map shows that a 'canyon effect' in between multistoried buildings with slightly elevated temperature. Compared to surrounding areas.

5.6 FINAL FINDINGS

As part of the North Curtin Residential Area microclimate assessment, seven scenarios were modelled to evaluate the effectiveness of various heat mitigation strategies. The primary scenarios, FDS 1 and FDS 6 through to FDS 8, were the focus of this analysis, while FDS 2 through to FDS 5 provided additional insights to deepen the understanding of these strategies' effectiveness.

FDS 6, FDS 7 and FDS 8 used the indicative site layout including placement of trees as adopted by the ACT Government appointed Planners. Simulation showed that embedding different heat mitigation measures within this site layout can help achieve 'net-zero heat gain'.

The modelling results indicate that the North Curtin Residential Area can achieve net-zero heat gain across potential air temperature (at 1.5m height) surface temperature and TMRT by adhering at minimum to the following design specifications which are consistent with FDS 6, FDS 7 and FDS 8:

- No more than 21% of the area covered by buildings (with high reflectivity materials used).
- No more than 17% of the area covered by pavement (with high reflectivity materials used).
- No more than 9% of the area used for roads (low reflective material permissible).
- At least 53% of the area contains vegetation with minimum 29% tree canopy cover (30% tree canopy cover with matured trees is recommended given potential variability in simulation results).
- At least 36% of vegetated areas must have capacity to hold moisture for longer using means including soil irrigation, wetlands, and raingardens.

Simulations suggest that these thresholds are likely to help the future North Curtin Residential Area development achieve a 'no net heat gain' given all these heat mitigation measures as tested in this simulation are implemented.

It is noted that heat distribution across the site can be variable and localised and depends on site characteristics, specifically on positioning of trees, and irrigated green areas. Therefore, to ensure the maximum heat mitigation benefits using tree canopy cover and vegetation, it is critical to consider the placement of trees, tree morphological characteristics (e.g., plant structure, canopy size, density, transpiration rate), topography, surface materials, urban geometry, and street orientation). Isolated trees may have less influence on shade provision and mean radiant temperature than clustered trees. Some of the observations from the study that are also consistent with wider knowledge in the literature are below:

- Street trees are likely to be more effective at reducing daytime thermal climate index in wide, open streets where building shade is absent.
- The heat mitigation benefits of trees can be significantly hampered in extremely hot and dry conditions (Gao, Feng, & Santamouris, 2024). When the air is very dry, the vapor pressure deficit is high, meaning the difference between the moisture in the air and the moisture the tree can release is large. This stresses trees and limits its ability to release water (due to lower stomatal conductance), reducing its cooling capacity when it's needed the most (Meili, et al., 2021).
- The irrigation of trees and vegetation is critical for it to achieve maximum cooling performance. For example, it has been found that for trees in Sydney to achieve the maximum cooling performance, water usage may need to increase by 20% (Knight, 2024).
- Irrigated courtyard grass in high-rises improves urban cooling, air quality, and biodiversity, fosters community and wellness, and enhances visual appeal compared to setback areas (Pelorosso, Gobattoni, & Leone, 2017) (Shashua-Bar, Pearlmutter, & Erell, 2009).
- Protecting, maintaining, and growing urban trees and vegetation requires long-term investment and planning. It is critical that trees are planted and maintained in such a way that they deliver the largest benefits possible for the cost of their investment (Coutts & Tapper, 2017).

5.6.1 GUIDELINE FOR FUTURE IMPLEMENTATION

This study conducted simulation to identify design thresholds for achieving a ‘no-net heat gain’ of the proposed Curtin Residential Area Development using an indicative site layout. Developed design thresholds provide some level of flexibility for final site design and their implementation. Based on the simulation, in theory, if these thresholds are met, ‘no net heat gain’ in the precinct can be achieved. However, the following factors should be carefully considered while implementing the site development.

Accommodating changes in site layout

It is noted that the site layout tested in this assessment is an early concept design, and the final site design may require amendments. An amended site layout to that tested in this study will require careful consideration of the following:

Layout of trees and vegetated areas:

Tree layout was found to have the most significant impact on heat reduction. For example, positioning trees in the high ‘human traffic’ areas (e.g., walkways and common outdoor areas) is critical for reducing heat exposure to outdoor users of the precinct. Irrigated vegetated areas in the courtyard is also recommended when compared to setback areas. Specifically, the layout of vegetations around the buildings are critical to conserve to ensure an optimal localised microclimate within the 'lived-in spaces' (i.e., spaces in between buildings) that does not have excessive levels of heat. Evidence of this trend was found when comparing heat maps of FDS 1 and FDS 6, as FDS 6 have trees and irrigated areas in the courtyard showing clear temperature reduction and better thermal comfort in the communal spaces (see Figure 19).

It is recommended that irrigated grass areas should be accommodated in the courtyards, similar to what is tested in the simulation. In general, having irrigated grass in the courtyard of a high-rise complex offers enhanced environmental, social, and aesthetic benefits compared to setback areas. Courtyards provide centralised green spaces that are more accessible and visible to residents, promoting outdoor activities and social interaction. The grass helps regulate temperatures by reducing heat absorption, creating a cooler microclimate in densely urbanized areas which was observed in North Curtin Residential Area simulation. Conversely, grass in setback areas is less utilised, often serving as passive green zones.

Layout of buildings:

Any change in building layout should consider the dominant wind direction of the site and avoid creating any ‘canyon impact’ where heat can be trapped in a particular pocket and can elevate temperature in those pockets. However, the results from the study suggest that there are some areas of flexibility, particularly around building height if all other mitigation requirements are fulfilled.

Staged development of site

It is understood that the North Curtin Residential Area development will be progressively implemented over number of years. Accordingly, to manage heat throughout the development of the site, a flexible and staged approach should be used. Simulations have used matured trees which may not be possible to achieve at the site from the very beginning. Initially, smaller trees combined with water-sensitive urban design (WSUD) features like rain gardens and irrigation, cool roofs on buildings, and cool pavement for footpaths will help reduction of heat. Moist soil from native vegetation and reflective coatings will further aid cooling. Over time, as more buildings are constructed, cool roofs and cool pavements and trees will reduce heat through shade.

6 CONCLUSION

The microclimate assessment of the North Curtin Residential Area modelled seven different design scenarios, with scenarios four through eight all successfully achieved ‘net-zero heat gain’ passing. Additionally, findings show there is some flexibility in building heights so long as other requirements are met, as modelling demonstrated little change between scenarios when building height was increased. In summary, careful adherence to these design specifications and layout considerations can help effective heat management and comfortable living conditions in the North Curtin Residential Area.

APPENDICES

APPENDIX A: SOME KEY MODELLING PARAMETERS

Wind rose of Canberra.

Rose of Wind direction versus Wind speed in km/h (01 Mar 1939 to 15 Sep 2010)

Custom times selected, refer to attached note for details

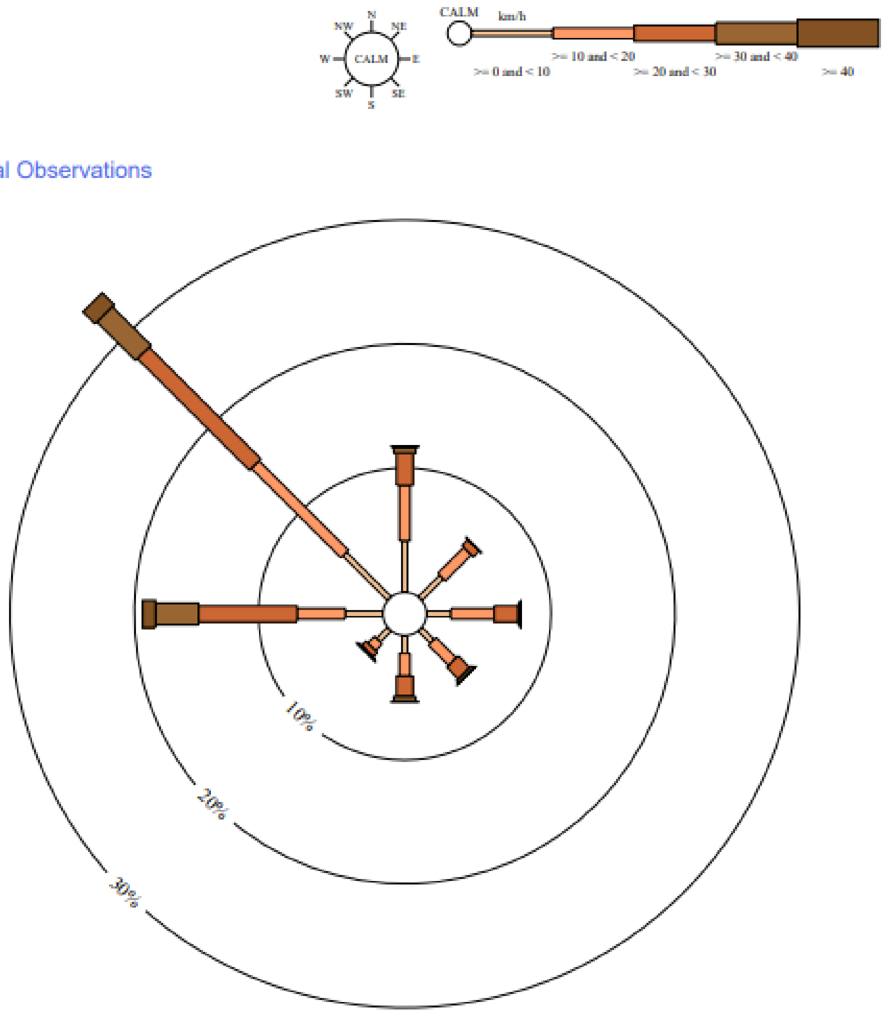
CANBERRA AIRPORT COMPARISON

Site No: 070014 • Opened Jan 1939 • Closed Dec 2010 • Latitude: -35.3049° • Longitude: 149.2014° • Elevation 578.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

3 pm
25592 Total Observations

Calm 9%



Australian Government
Bureau of Meteorology

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Figure 24: Canberra Airport Wind Rose (BoM data). Note that the dominant wind strength and direction is towards the West/North West.

Table 17: Adopted emissivity and albedo of different surfaces in the simulation.

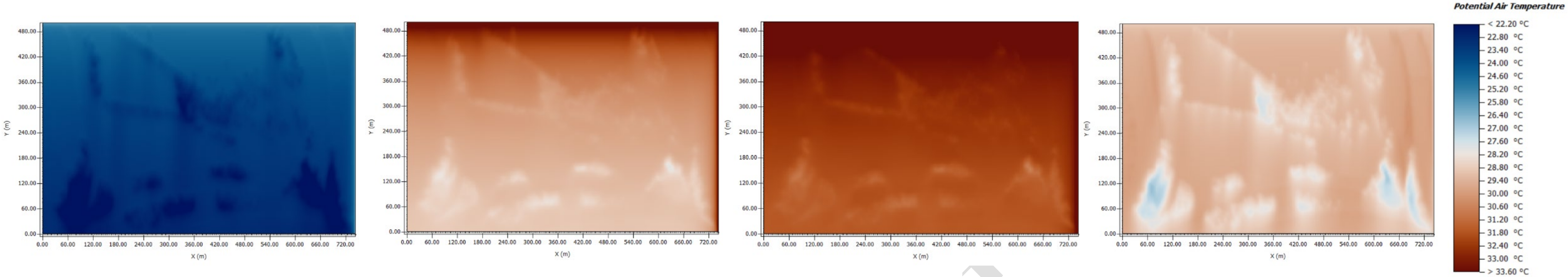
Material	Low Albedo (Reflection)	High Albedo (Reflection)	Emissivity
Soil (Non-irrigated)	0.2		0.9
Soil (Irrigated)	0.2		0.9
Asphalt Road	0.12	0.9	0.9
Concrete Pavement	0.5	0.9	0.9
Grass (100cm aver.dense)	0.2		0.97
Grass (25cm aver.dense)	0.2		0.97
Dry Grass 100cm	0.15		0.98
Shrub	0.2		0.97
Concrete Roof	0.3	0.9	0.9
Tiling Roof	0.3	0.9	0.93
Wall	0.3	0.9	0.94

APPENDIX B: HEAT MAPS FOR THE NORTH CURTIN RESIDENTIAL AREA

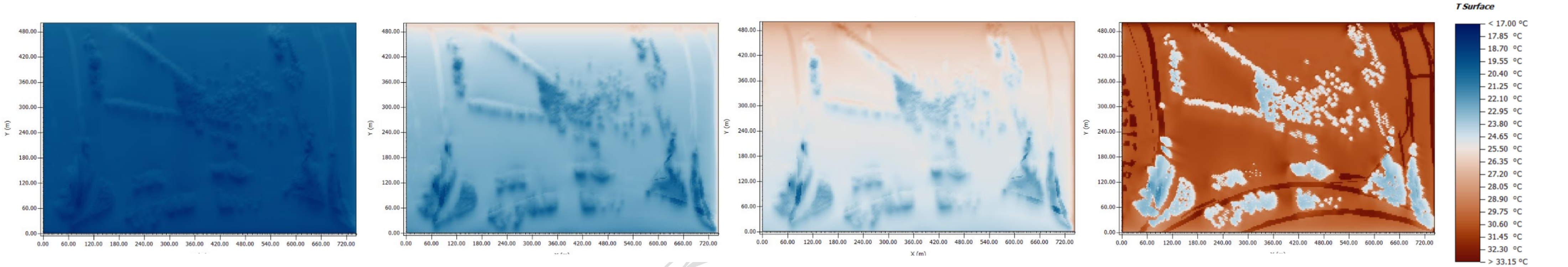
Refer to the following pages for the heat maps developed as part of this assessment for the North Curtin Residential Area:

1. Baseline
2. FDS 1
3. FDS 2
4. FDS 3
5. FDS 4
6. FDS 5
7. FDS 6
8. FDS 7, and
9. FDS 8.

BASELINE HEAT MAPS



9AM 12PM 3PM 9PM



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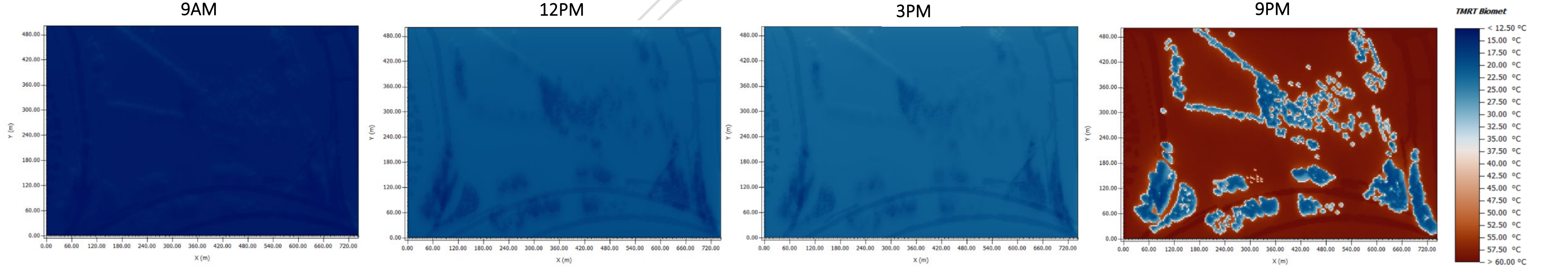

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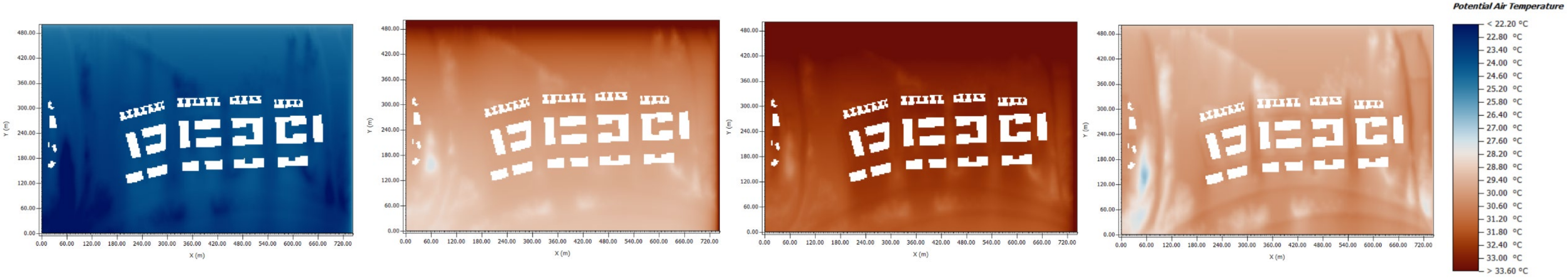

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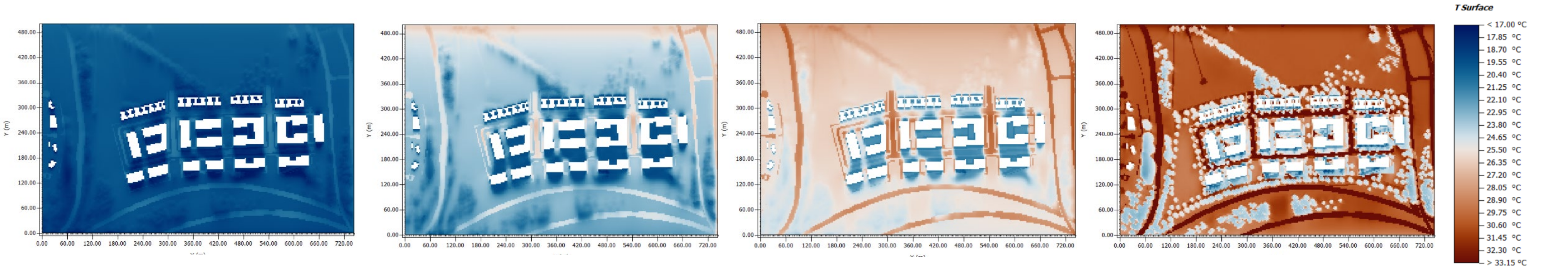
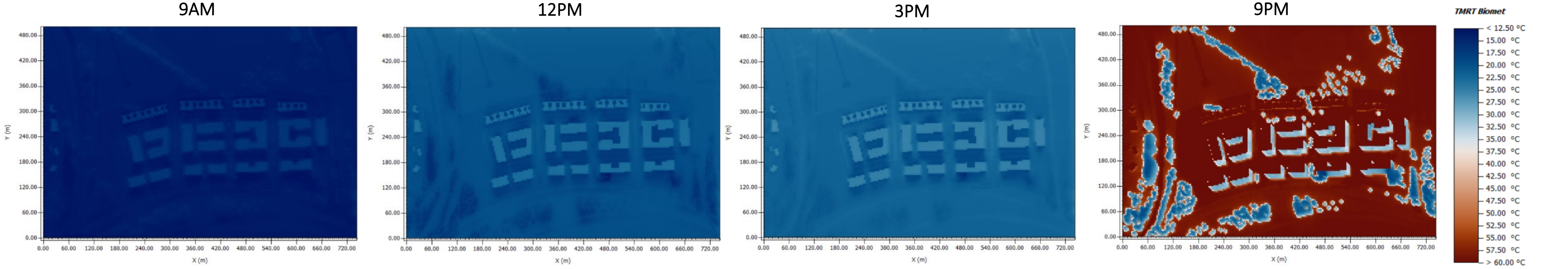
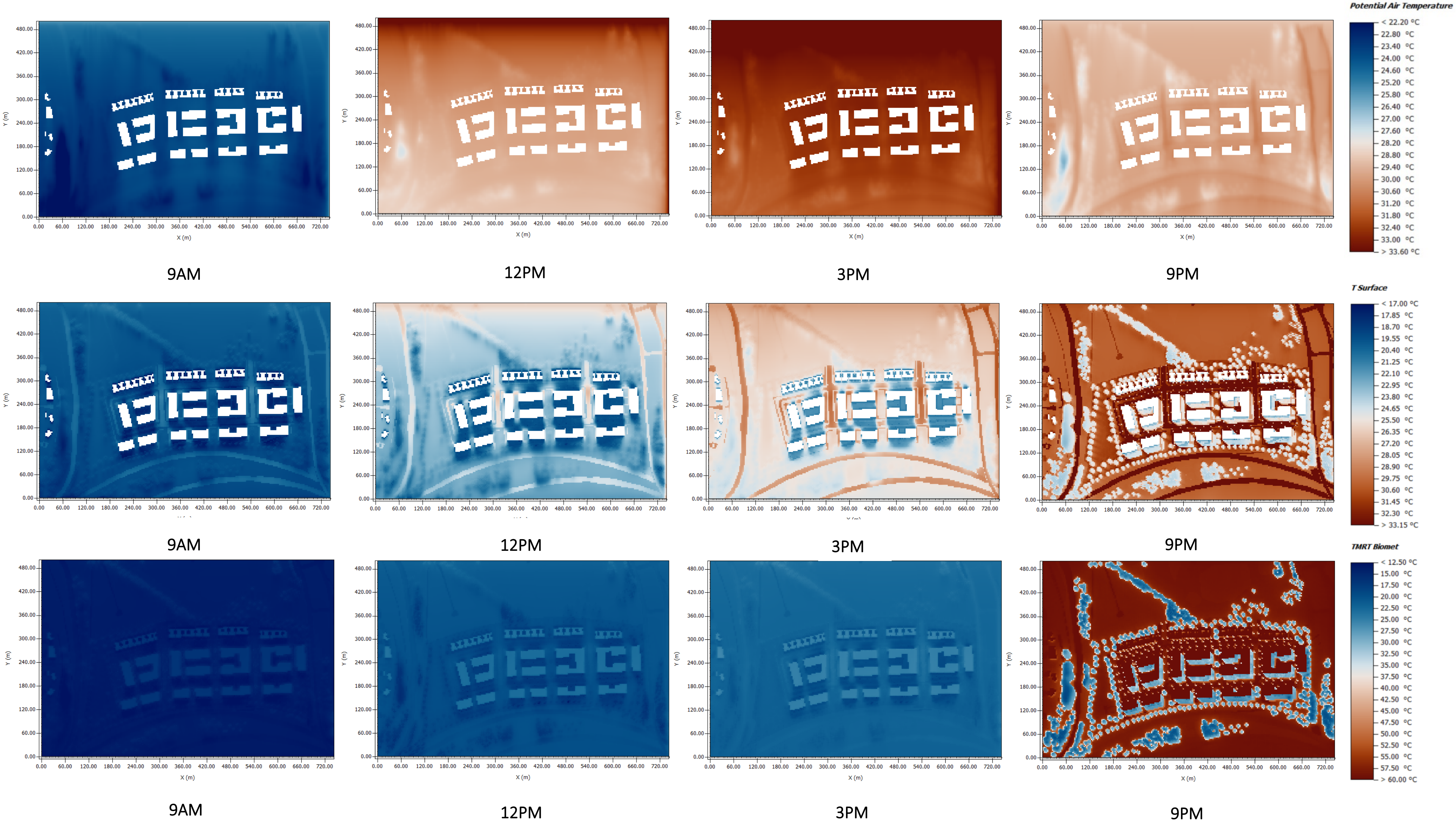


9AM 12PM 3PM 9PM

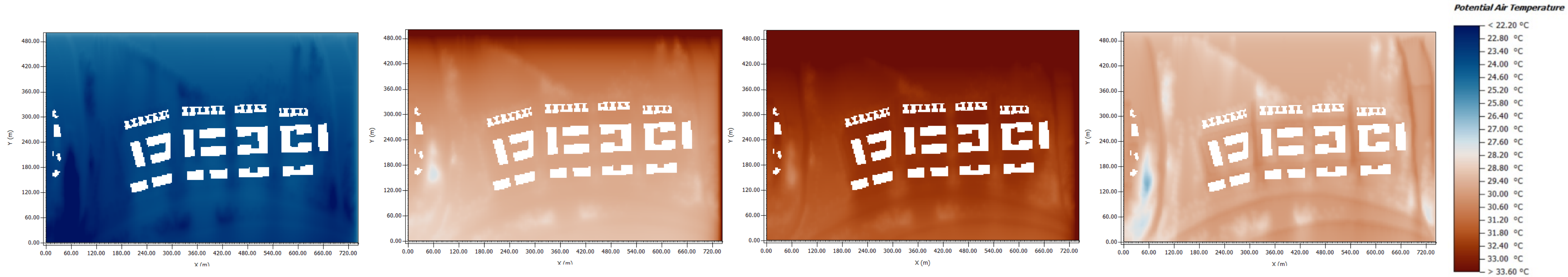


9AM 12PM 3PM 9PM

FDS 2 HEAT MAPS



FDS 3 HEAT MAPS



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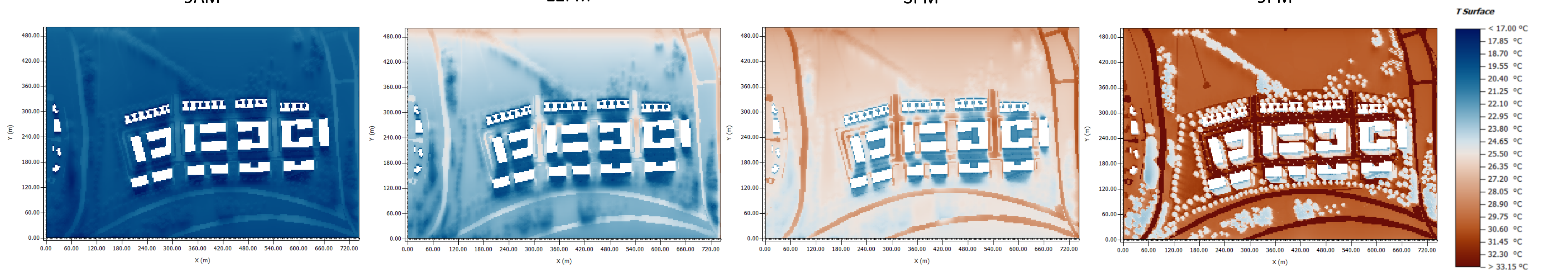

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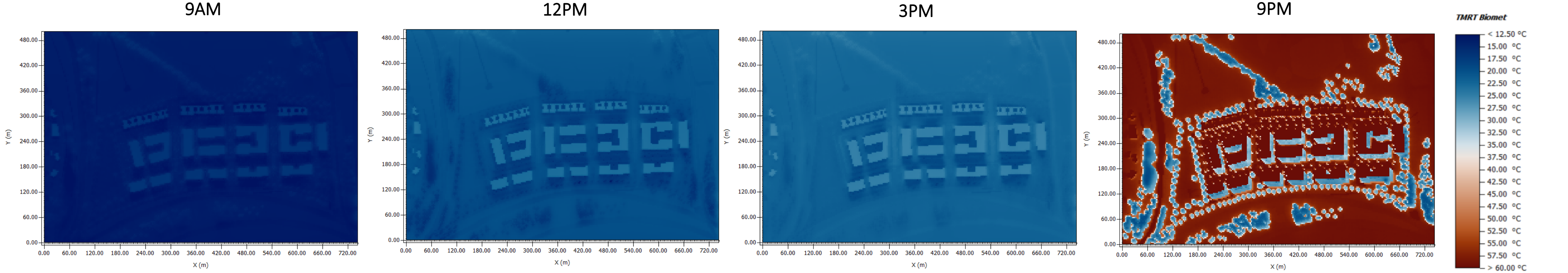
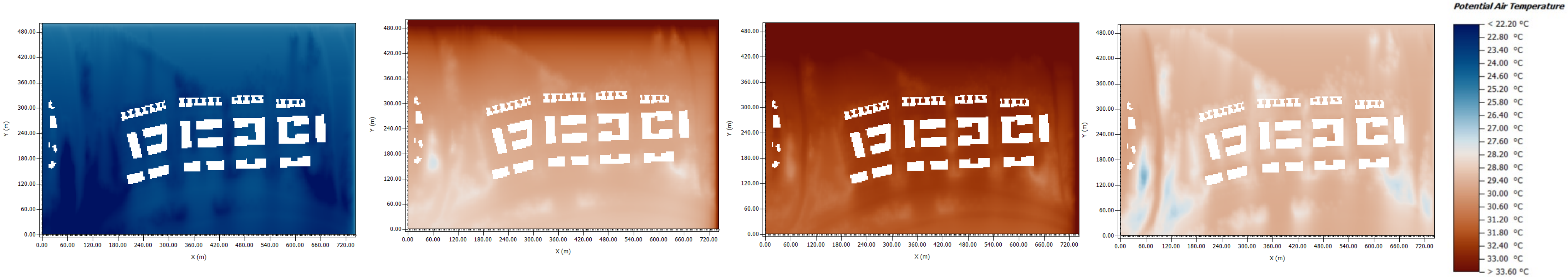


9AM 12PM 3PM 9PM

FDS 4 HEAT MAPS



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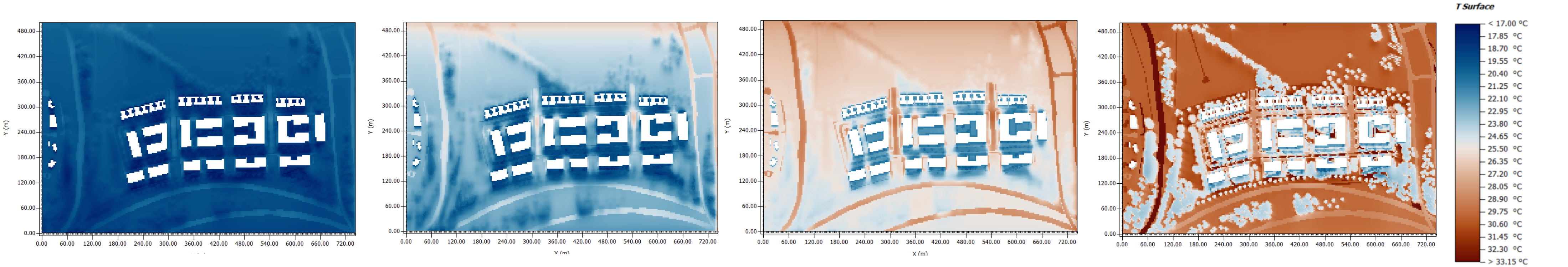

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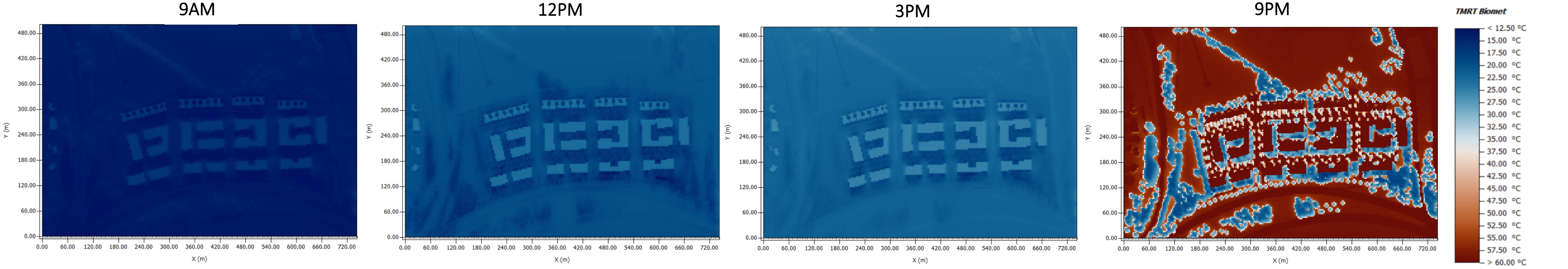
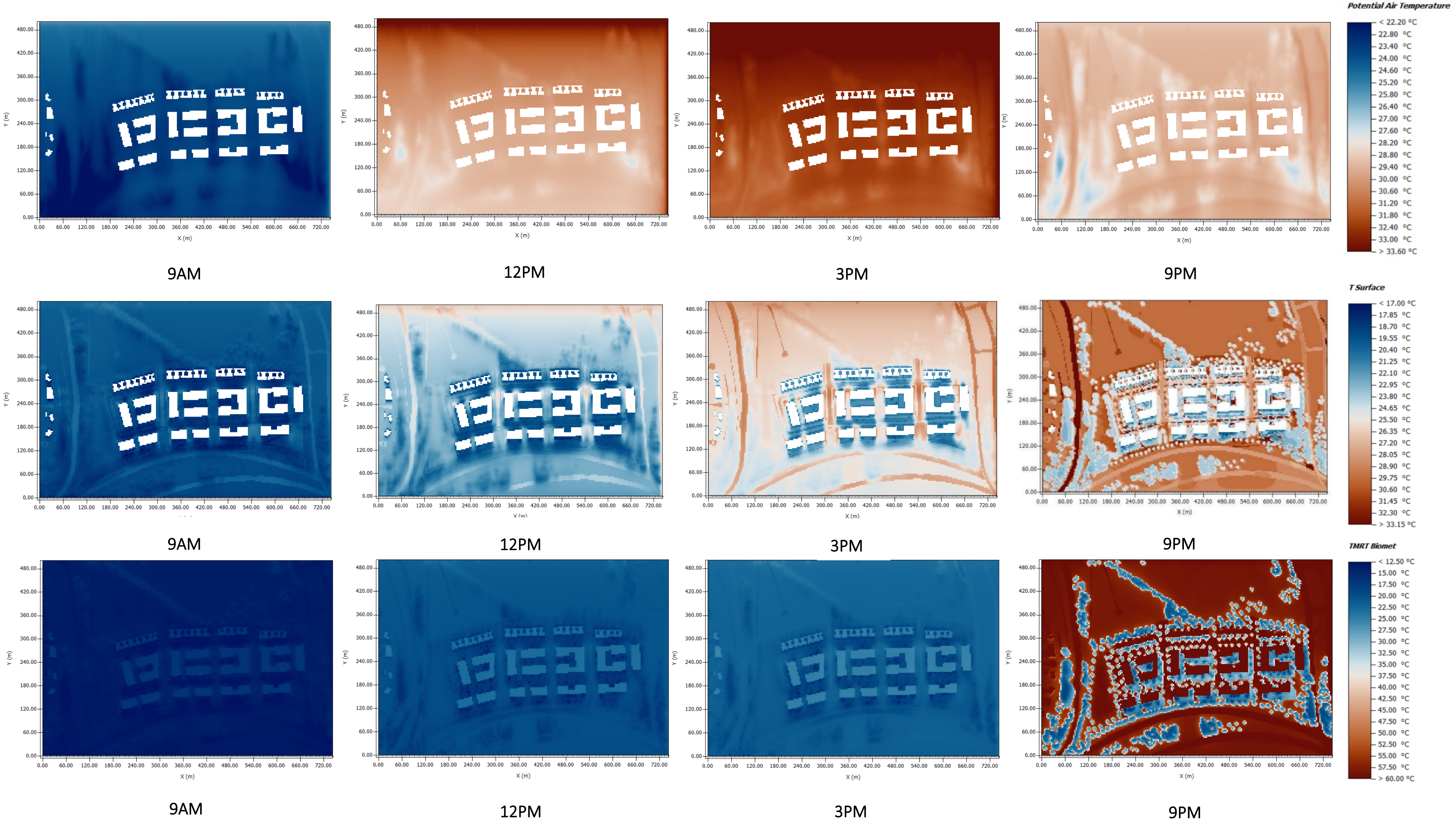
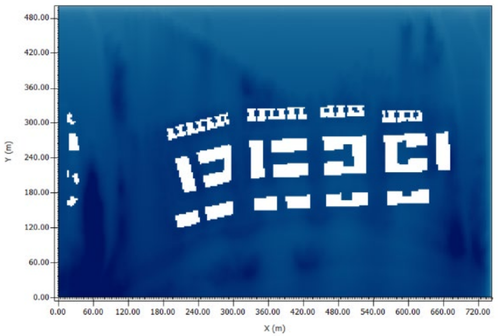


9AM 12PM 3PM 9PM

FDS 5 HEAT MAPS





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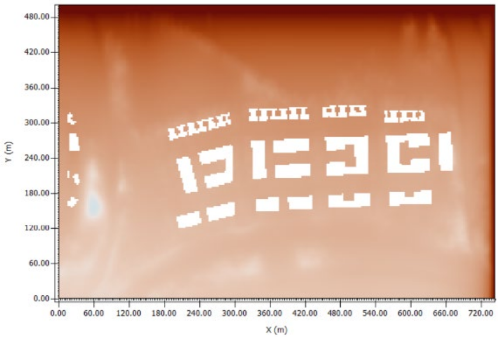

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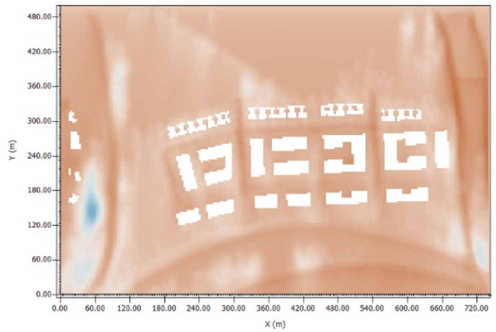

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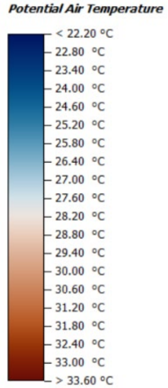

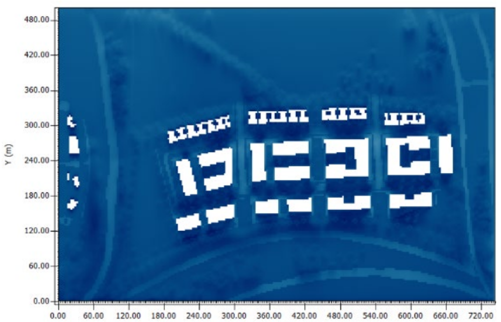

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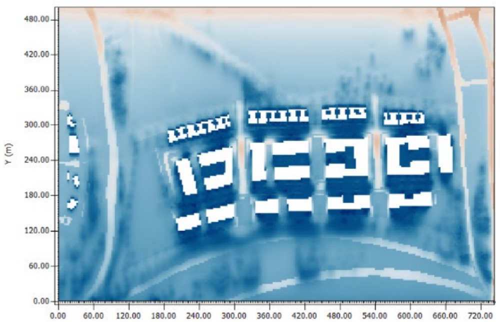

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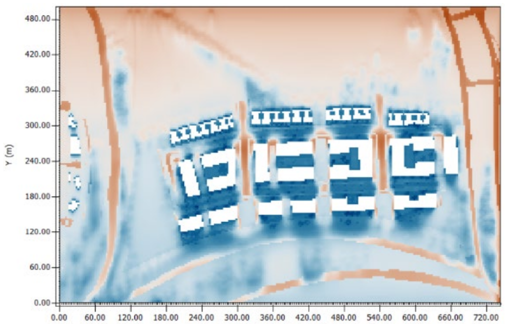

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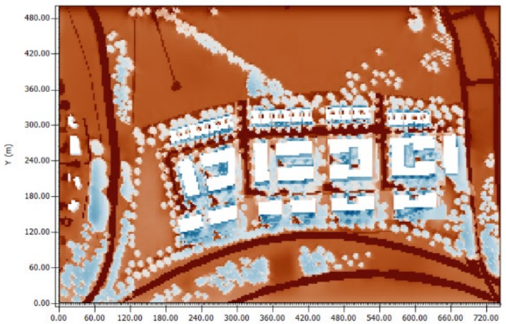

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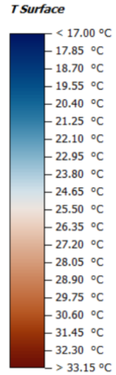

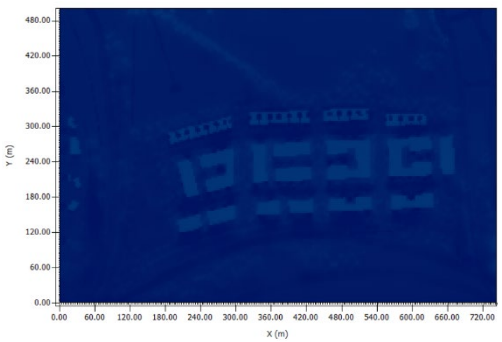

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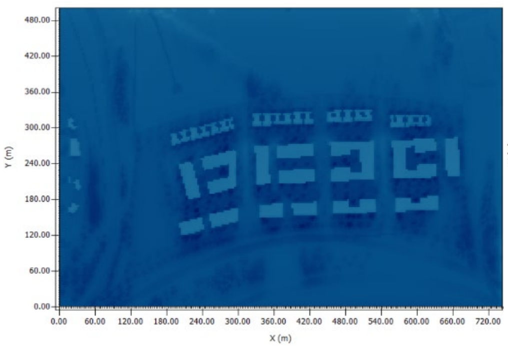

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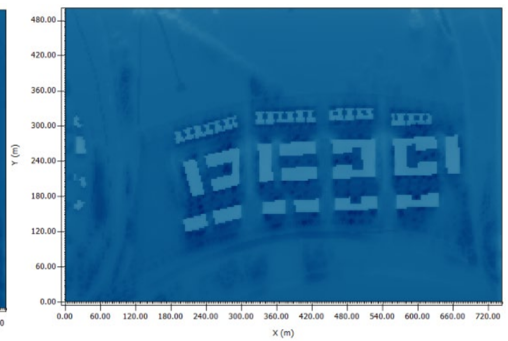

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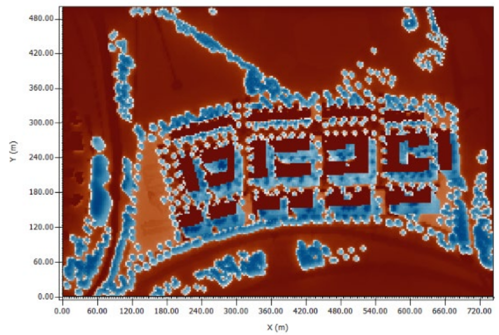

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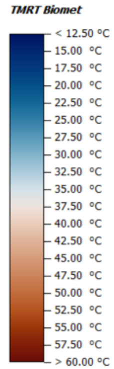
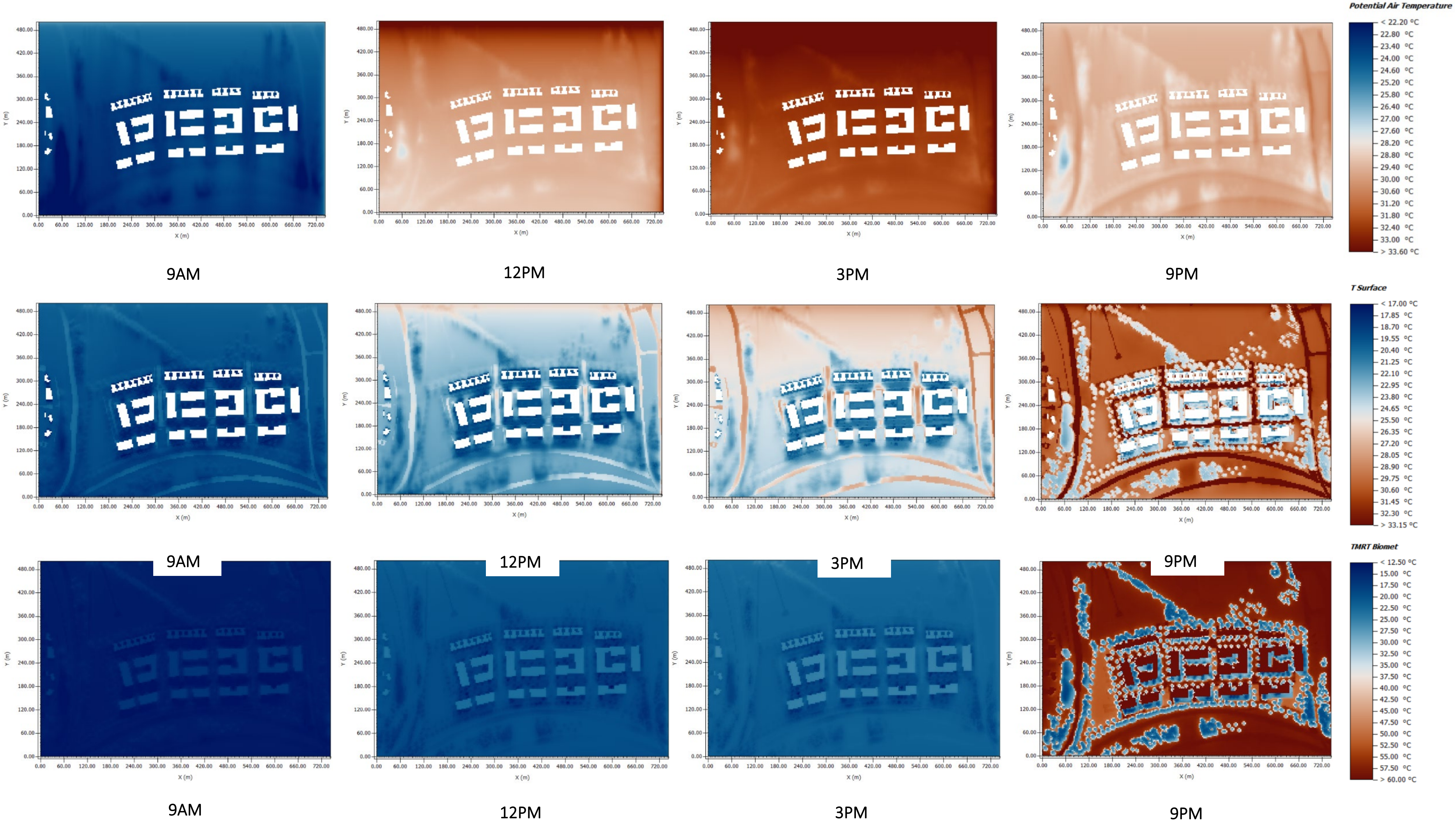
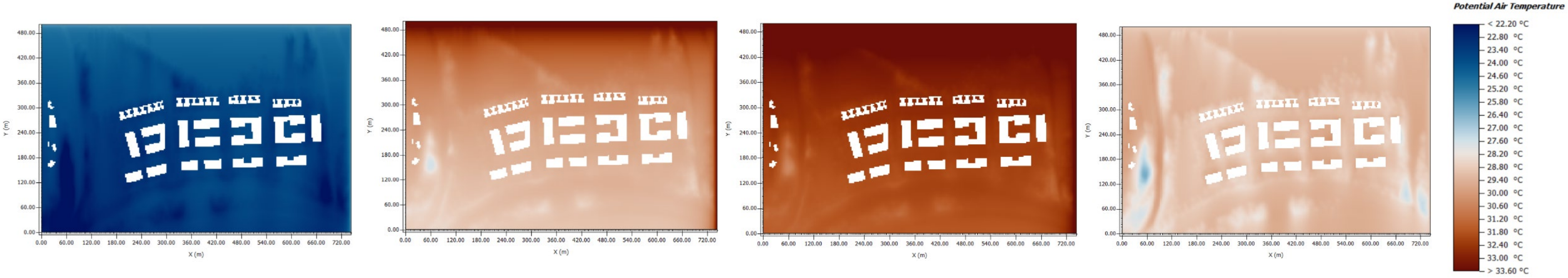


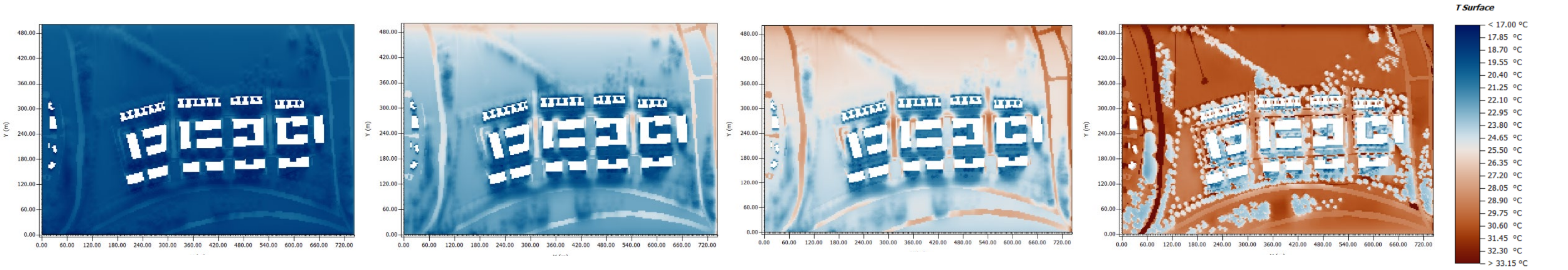
FDS 7 HEAT MAPS



FDS 8 HEAT MAPS



9AM 12PM 3PM 9PM



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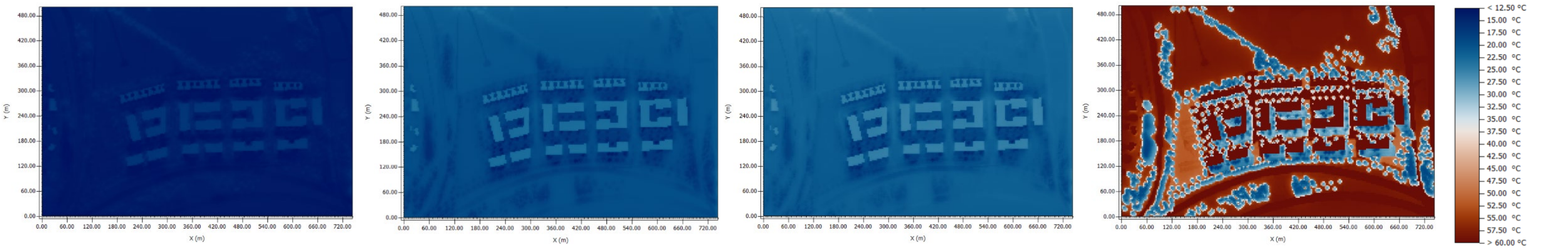

9AM 12PM 3PM 9PM

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